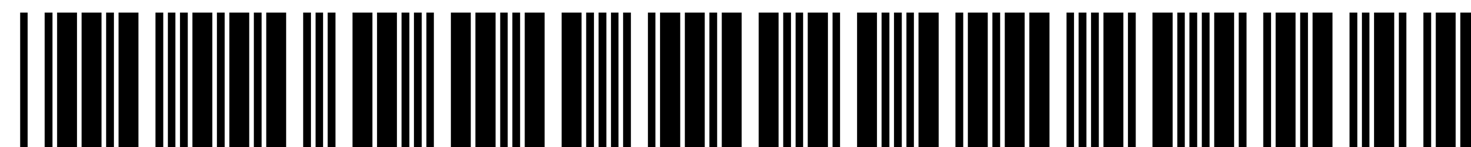
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(12) **United States Patent**
Kimura et al.

(10) **Patent No.: US 6,765,935 B2**
(45) **Date of Patent: Jul. 20, 2004**

(54) **SEMICONDUCTOR LASER MODULE, MANUFACTURING METHOD THEREOF AND OPTICAL AMPLIFIER**

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(73) Assignee: **The Furukawa Electric Co., Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/015,654**

(22) Filed: **Dec. 17, 2001**

(65) **Prior Publication Data**

US 2002/0093738 A1 Jul. 18, 2002

(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**[7] **A01S 3/13**
(52) **U.S. Cl.** **372/29.02**; 37/46
(58) **Field of Search** 372/29.01, 29.016, 372/29.02, 98–108, 29.014, 107, 20, 36

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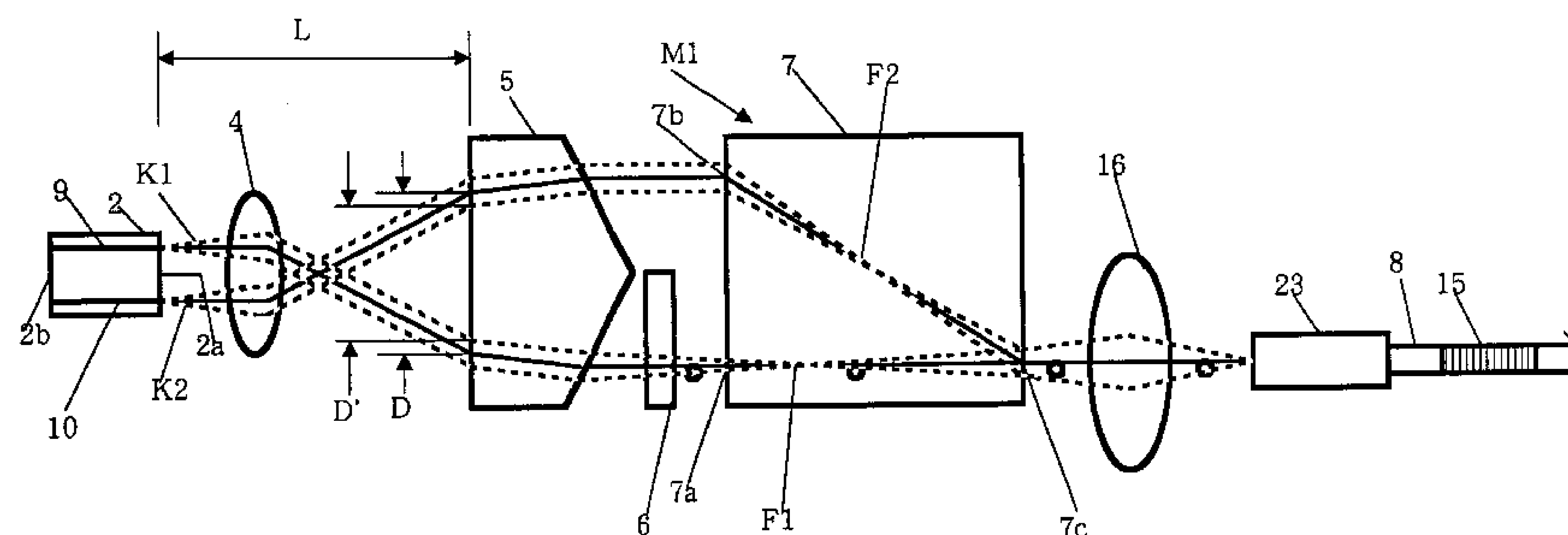
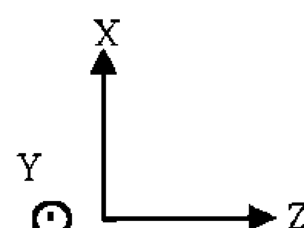
Primary Examiner—Paul Ip
Assistant Examiner—Tuan Nguyen
(74) *Attorney, Agent, or Firm*—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

(57) **ABSTRACT**

A semiconductor laser module includes a single semiconductor laser device having a first light emitting stripe and at least one other light emitting stripe which are aligned to respectively emit a first laser beam and at least one other laser beam through one edge surface. It also includes a first lens positioned so that the first laser beam and the at least one other laser beam emitted from the semiconductor laser device are incident thereon, the first lens configured to separate the first laser beam and the at least one other laser beam. A beam synthesizing member is included and has a first input part on which the first laser beam is incident, at least one other input part on which the at least one other laser beam is incident, and an output part from which the first laser beam emerging from the first input part and the at least one other laser beam emerging from the at least one other input part are multiplexed and emitted as a multiplexed laser beam. An optical fiber is positioned to receive the multiplexed laser beam therein.

67 Claims, 35 Drawing Sheets





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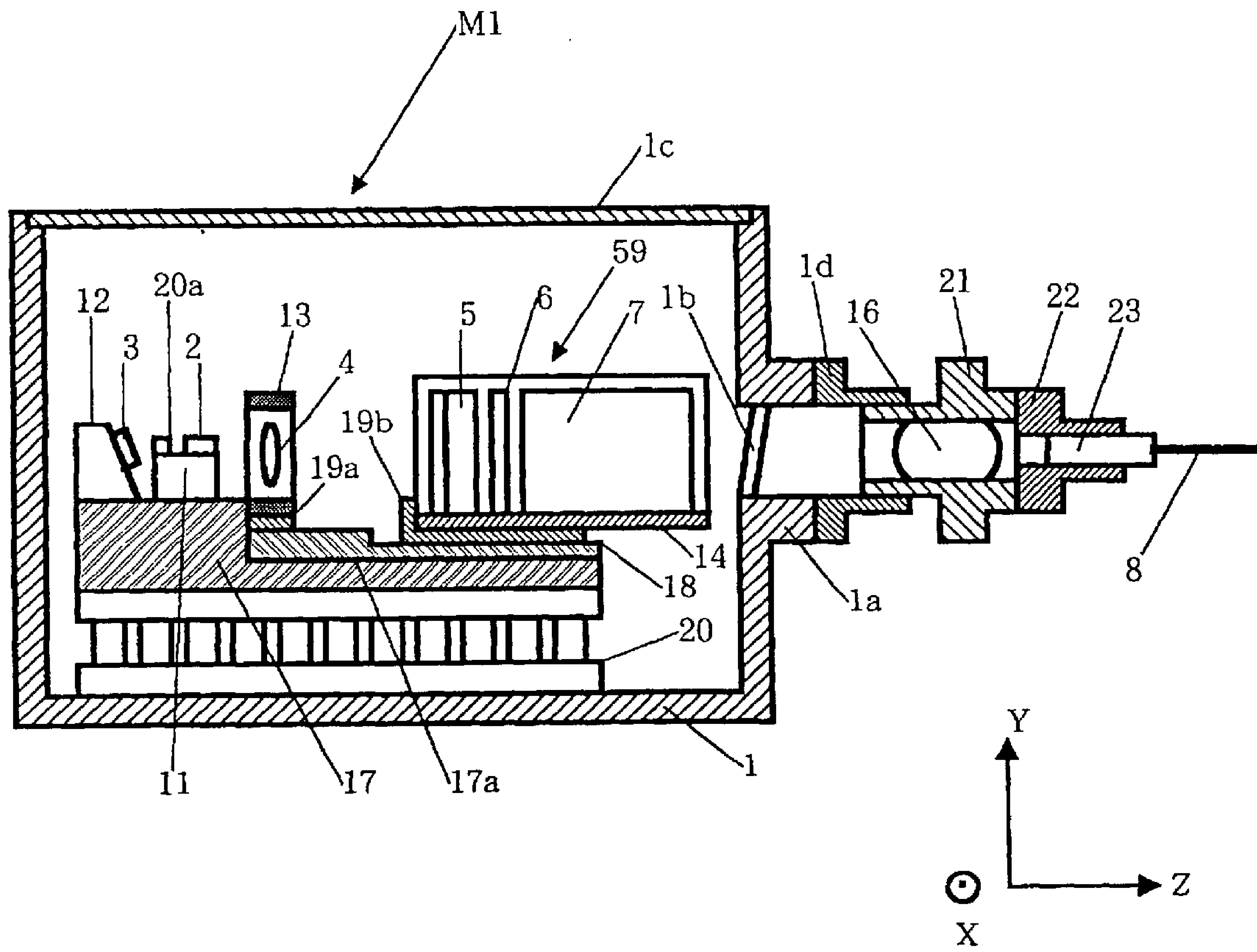

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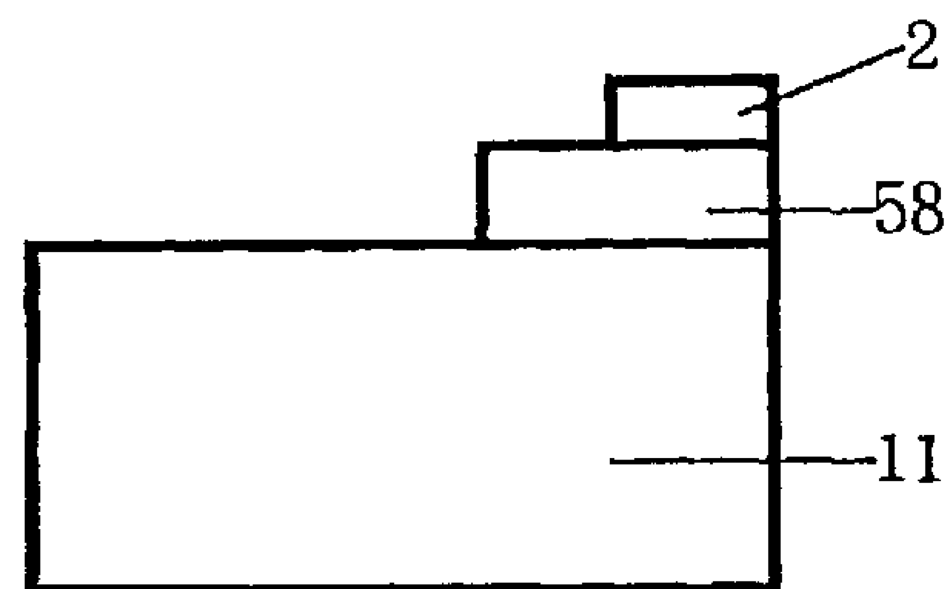

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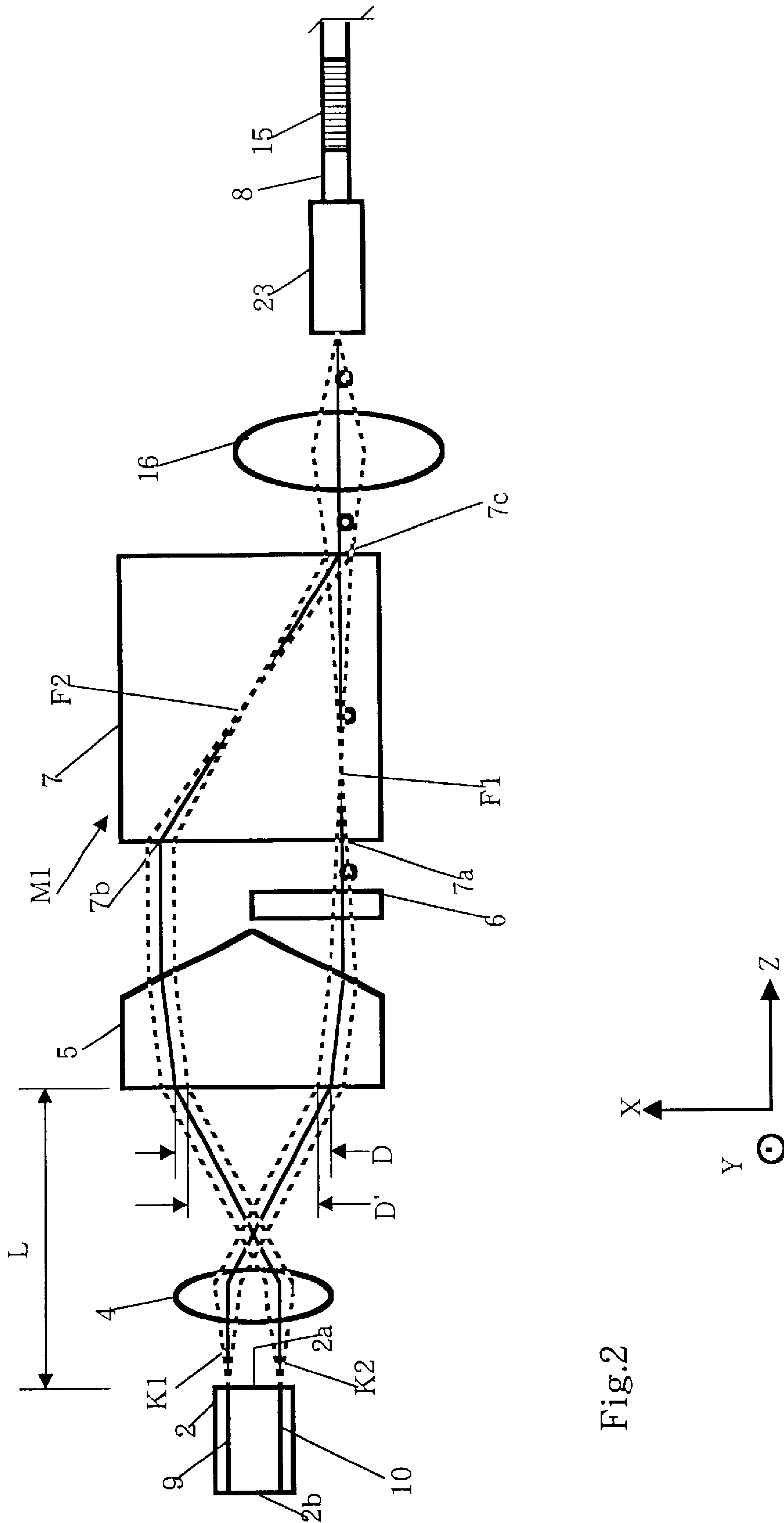

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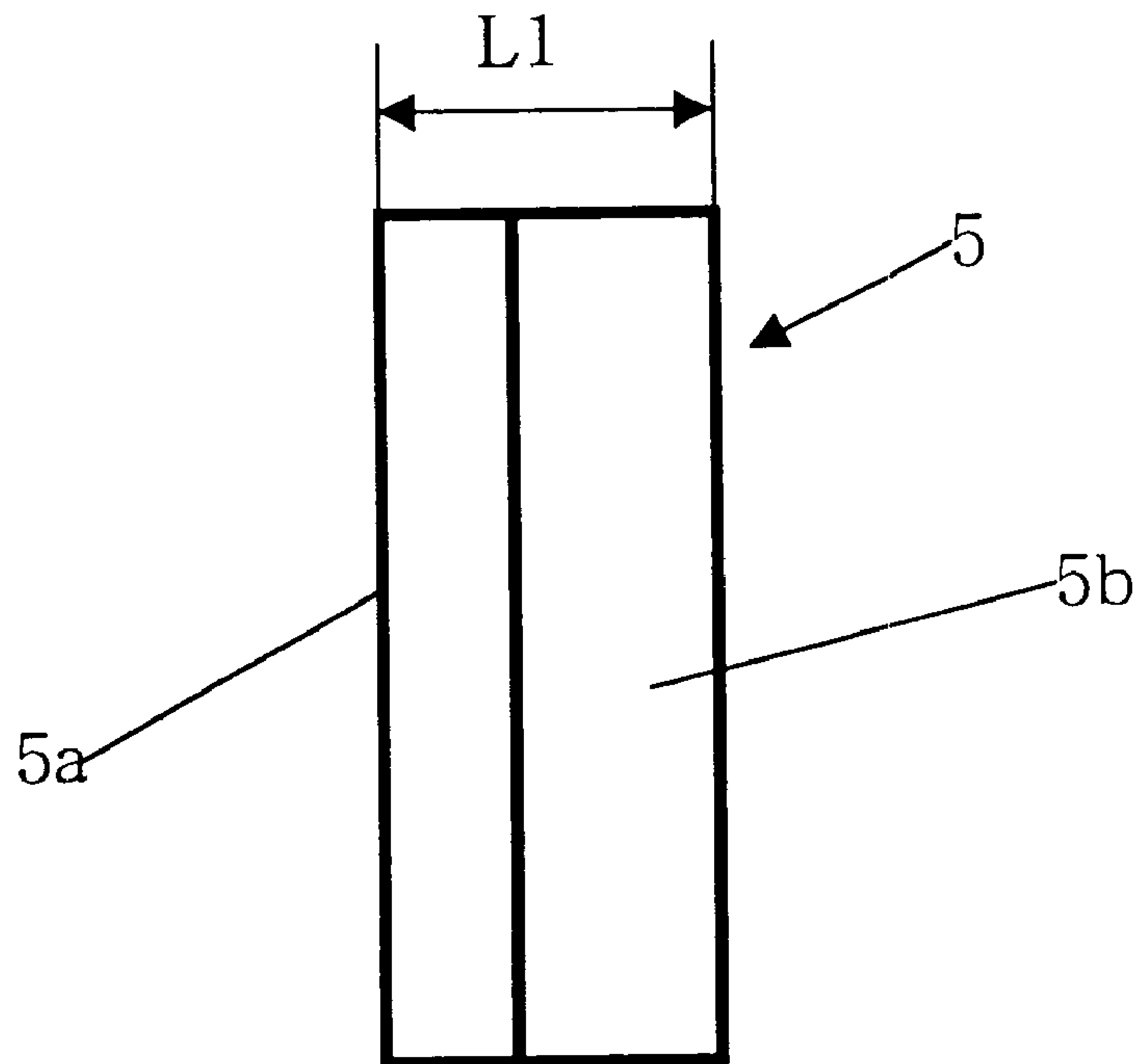

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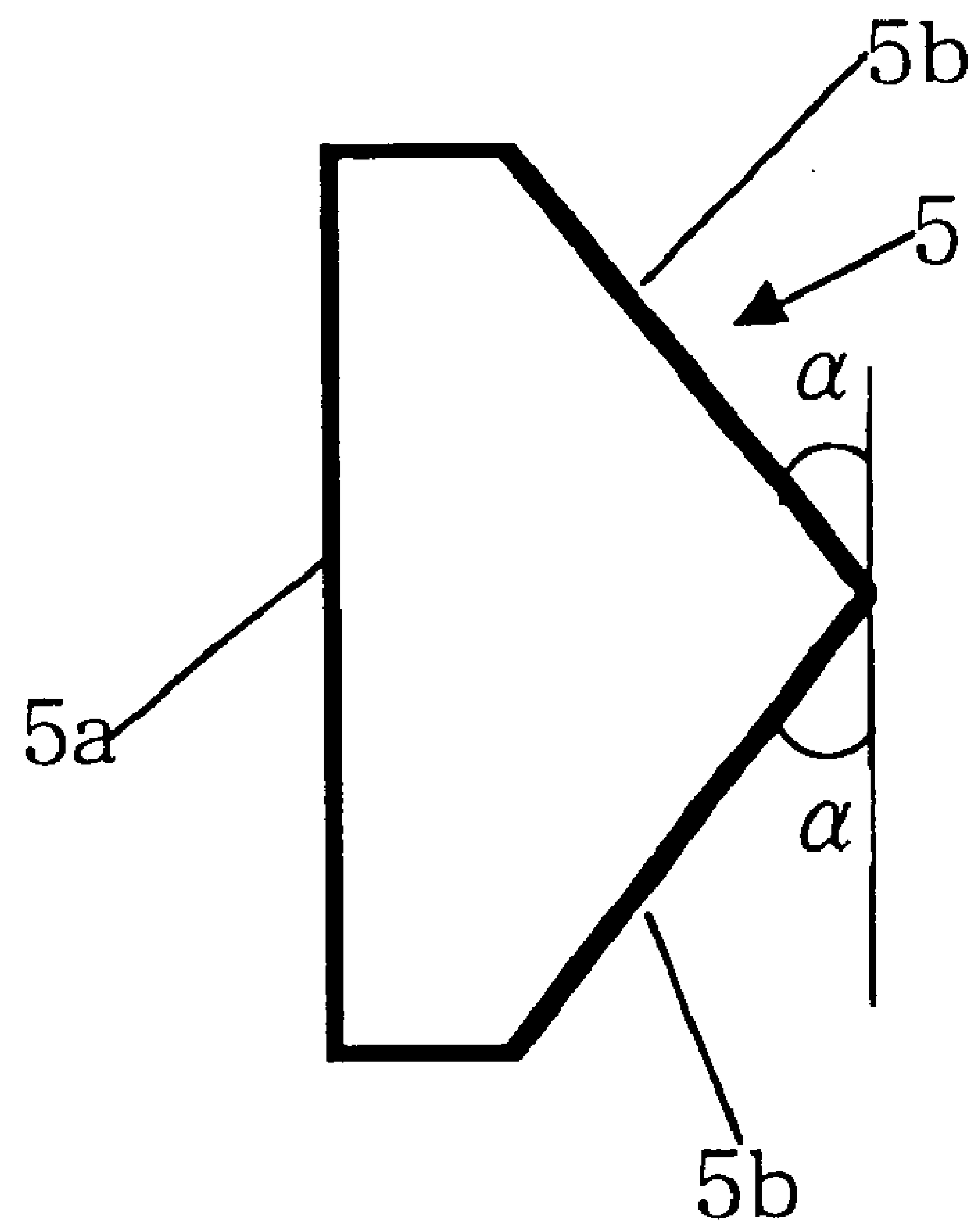

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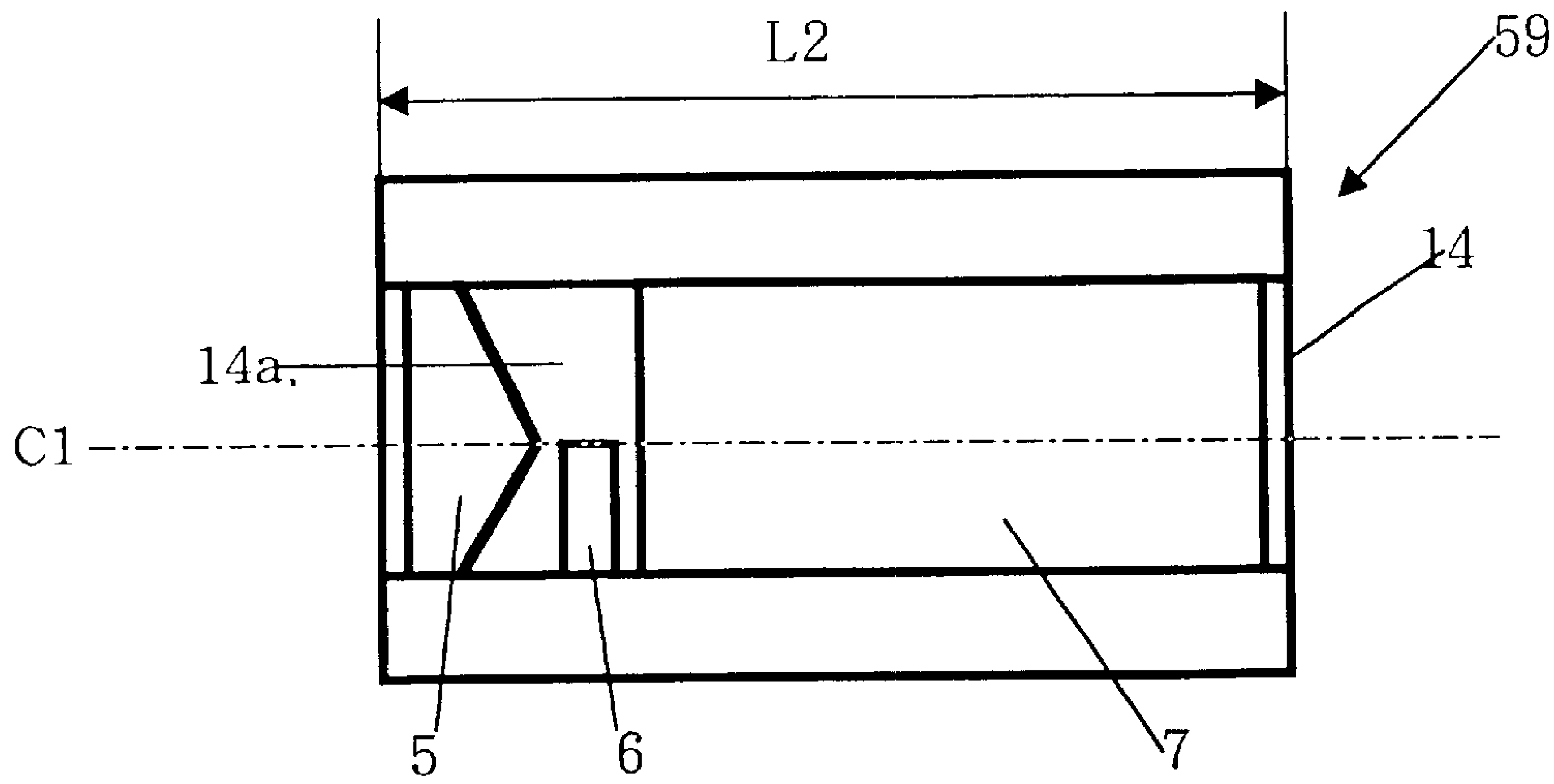

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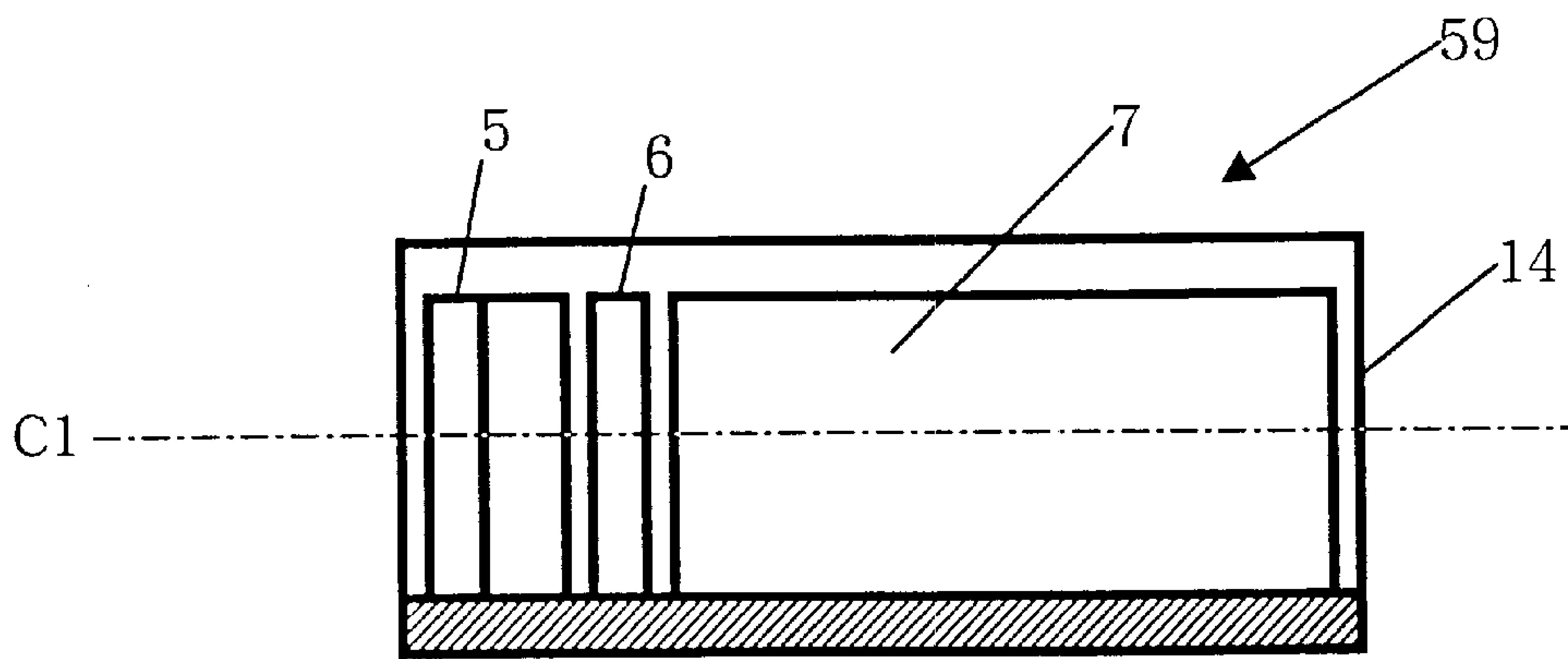

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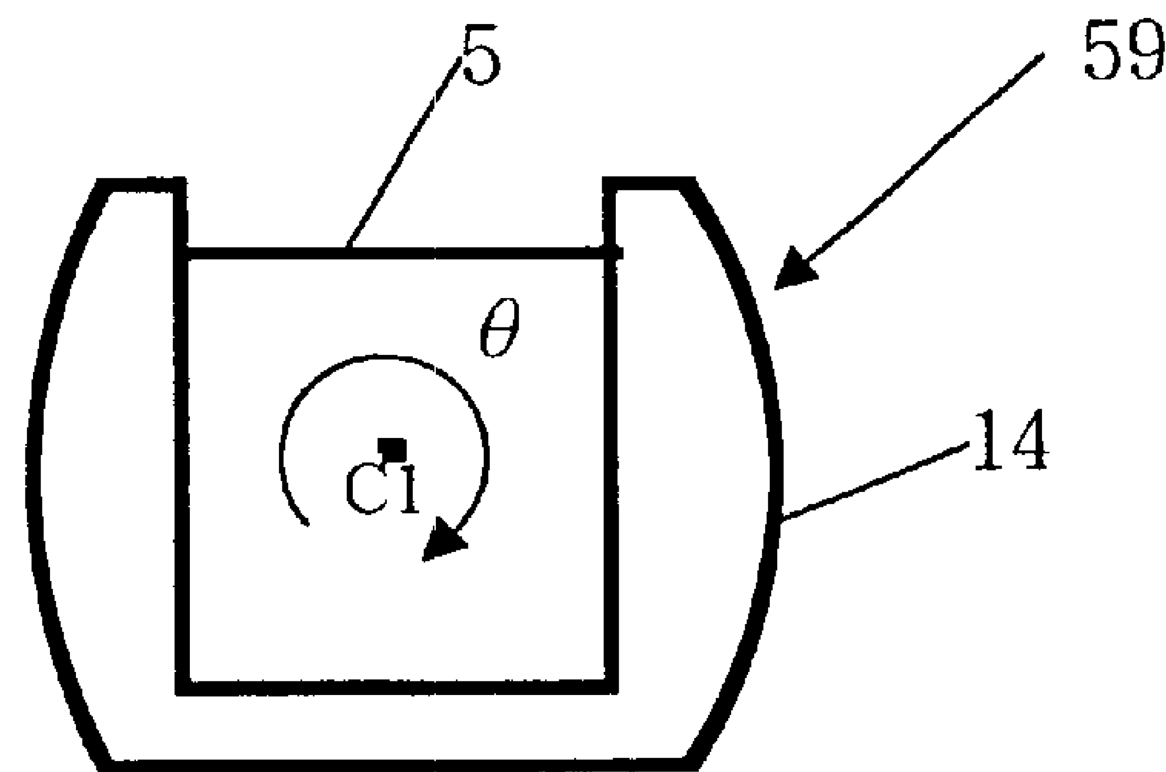

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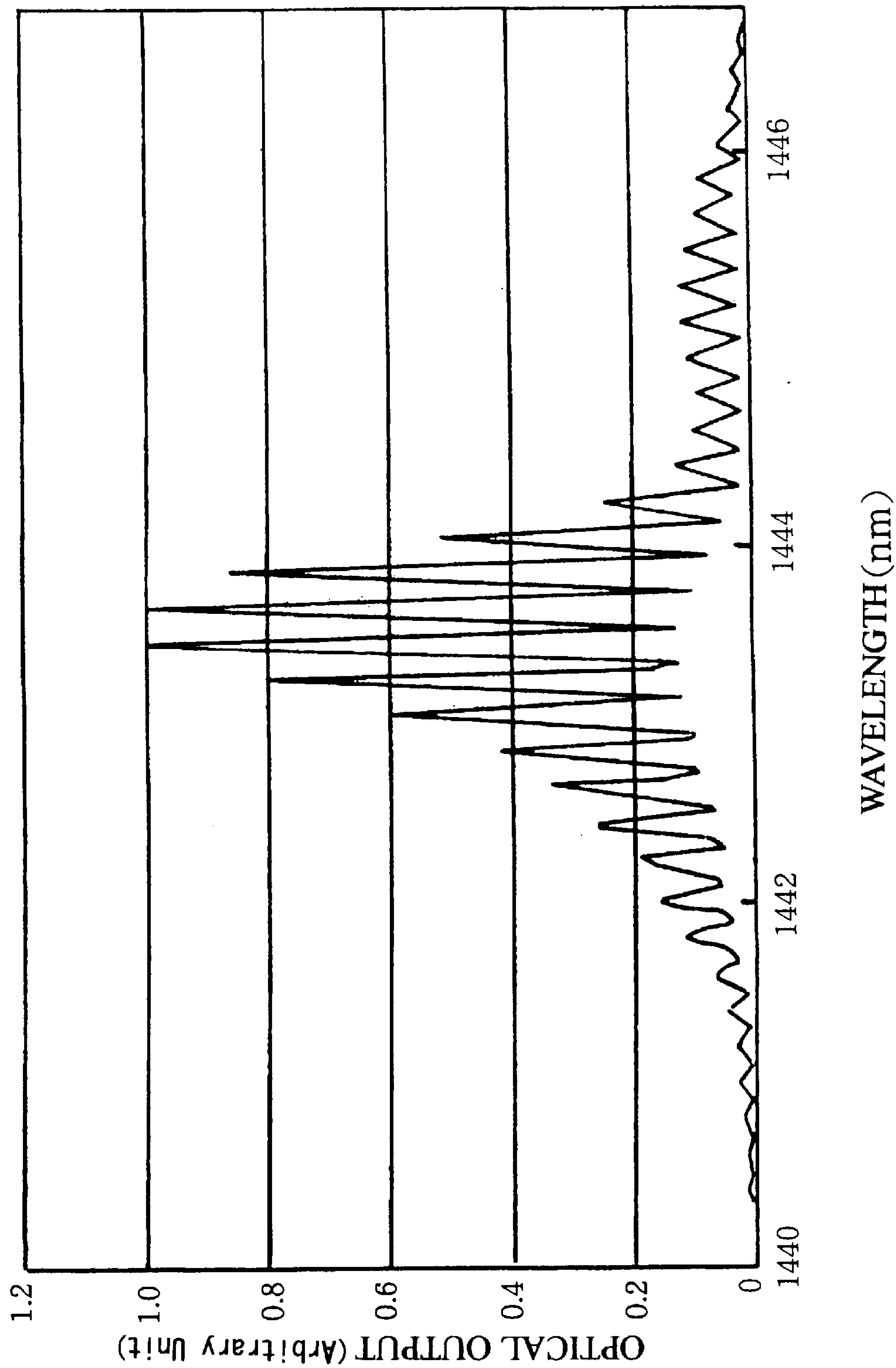
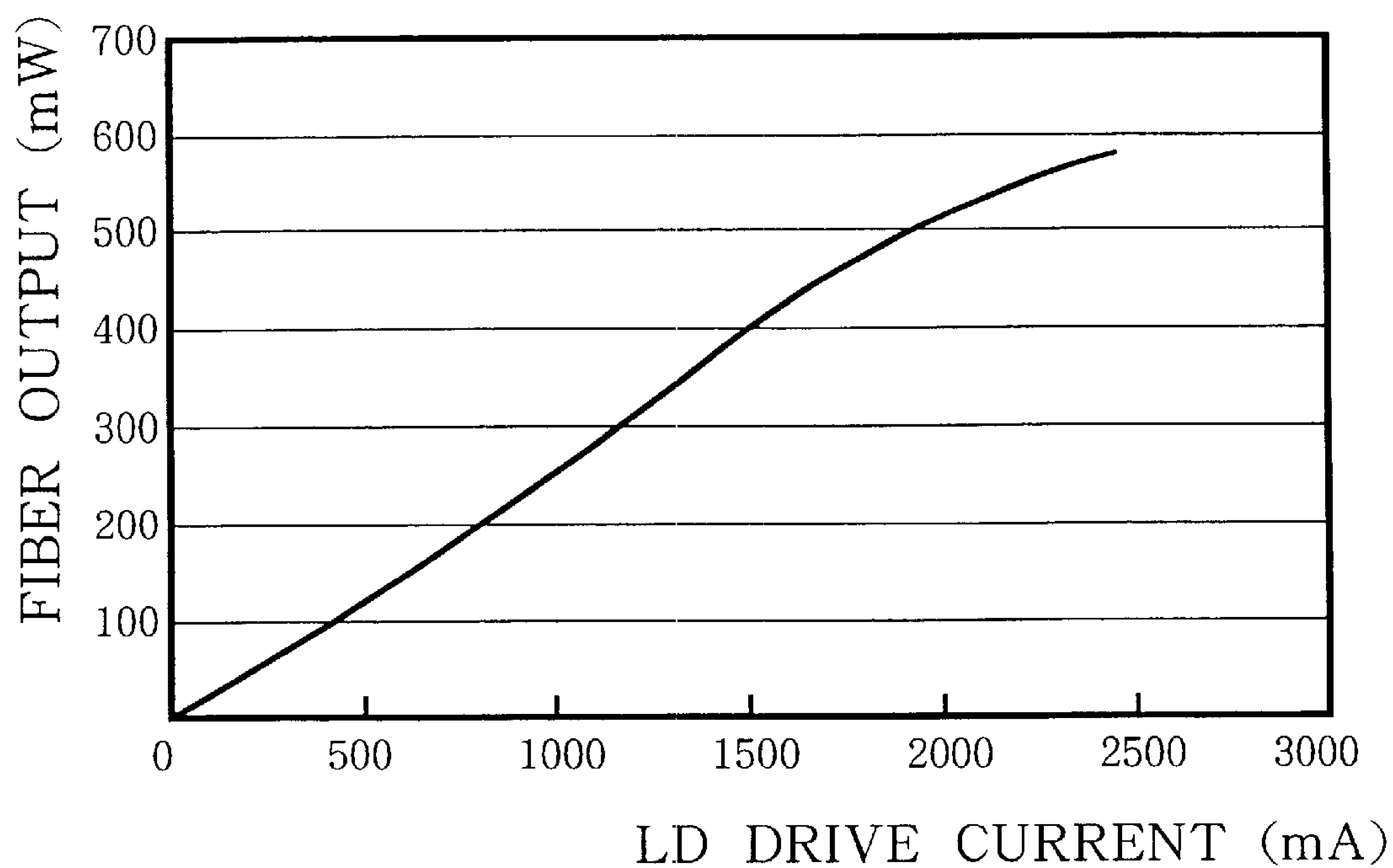


FIG. 5



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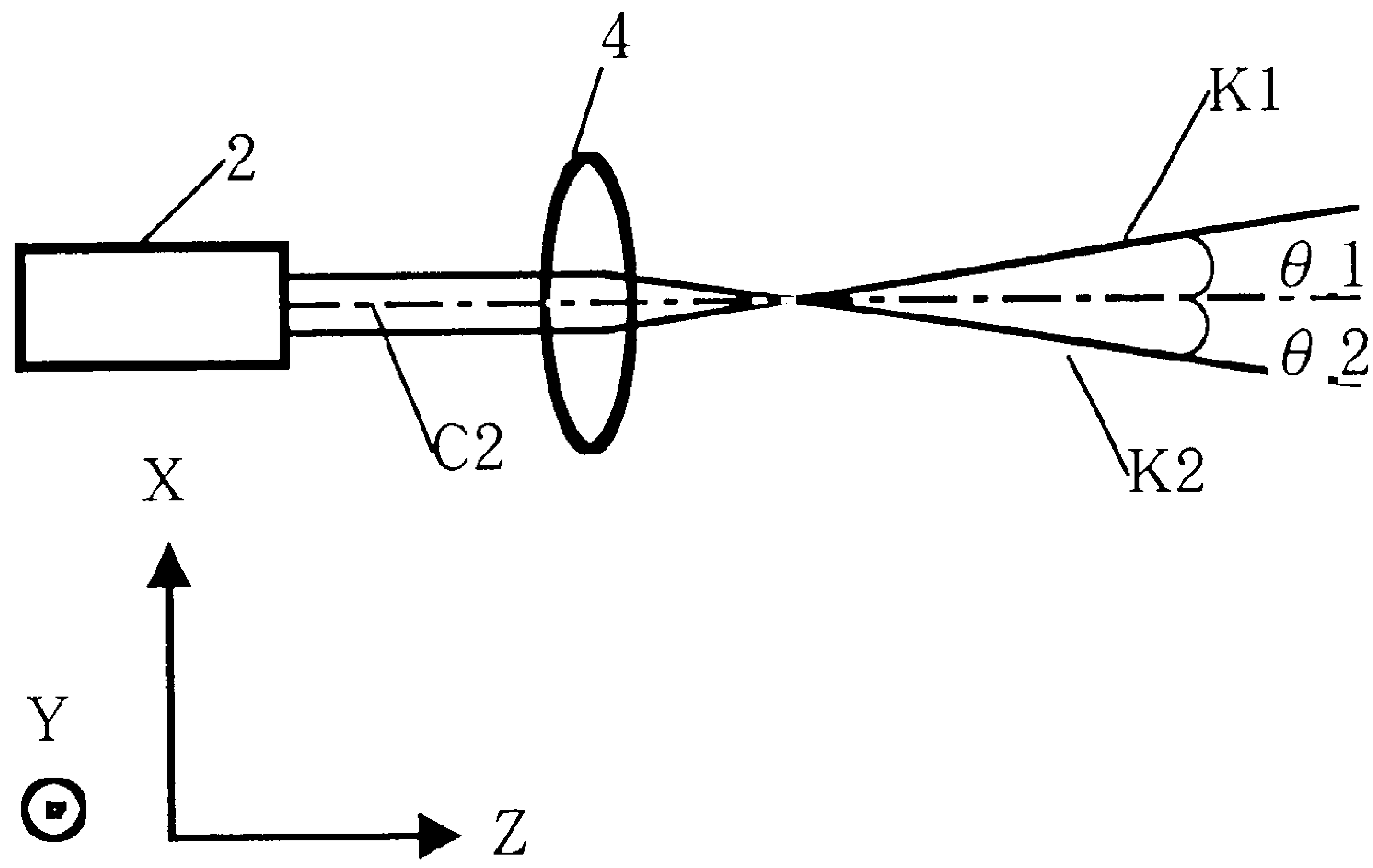

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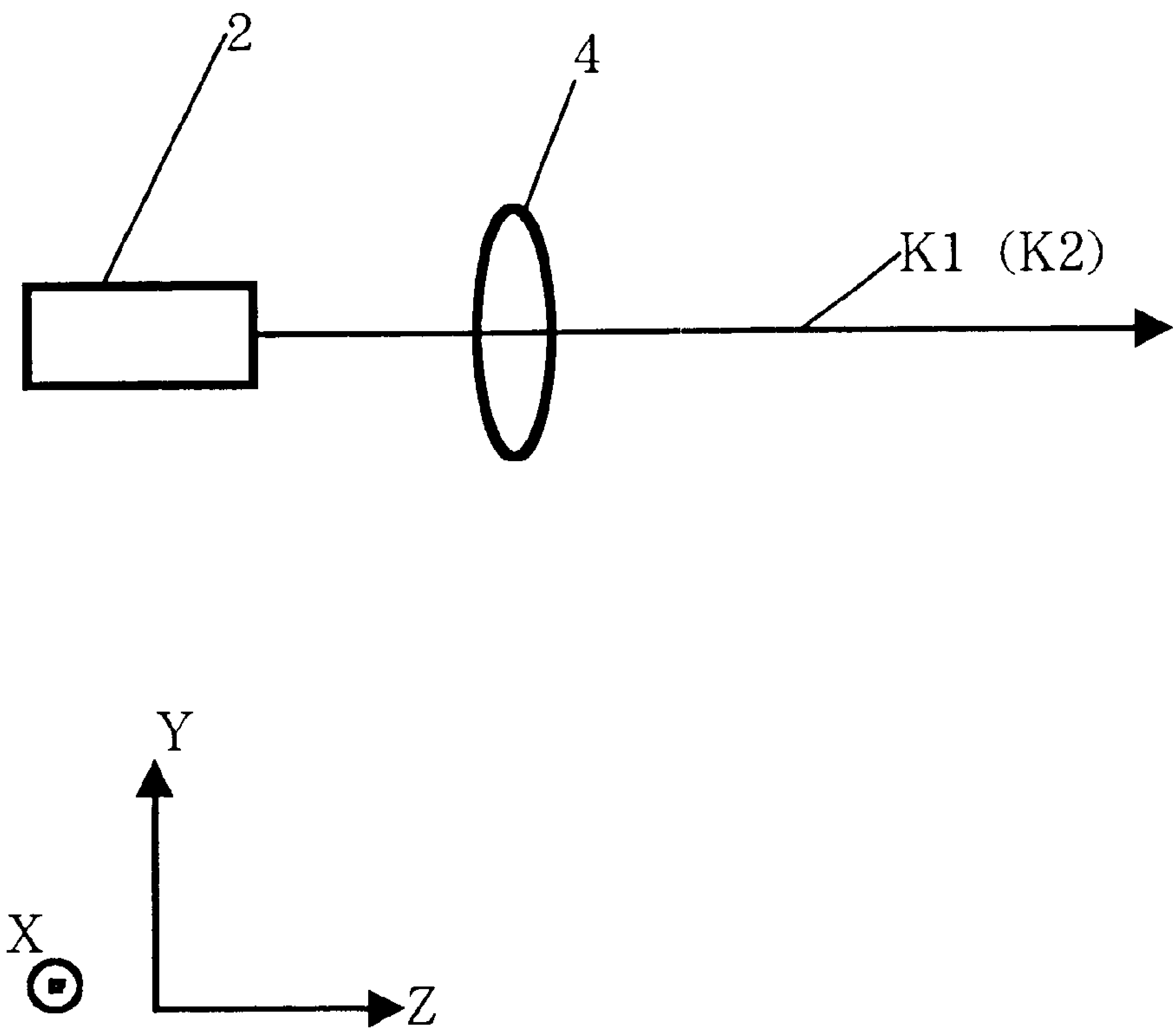

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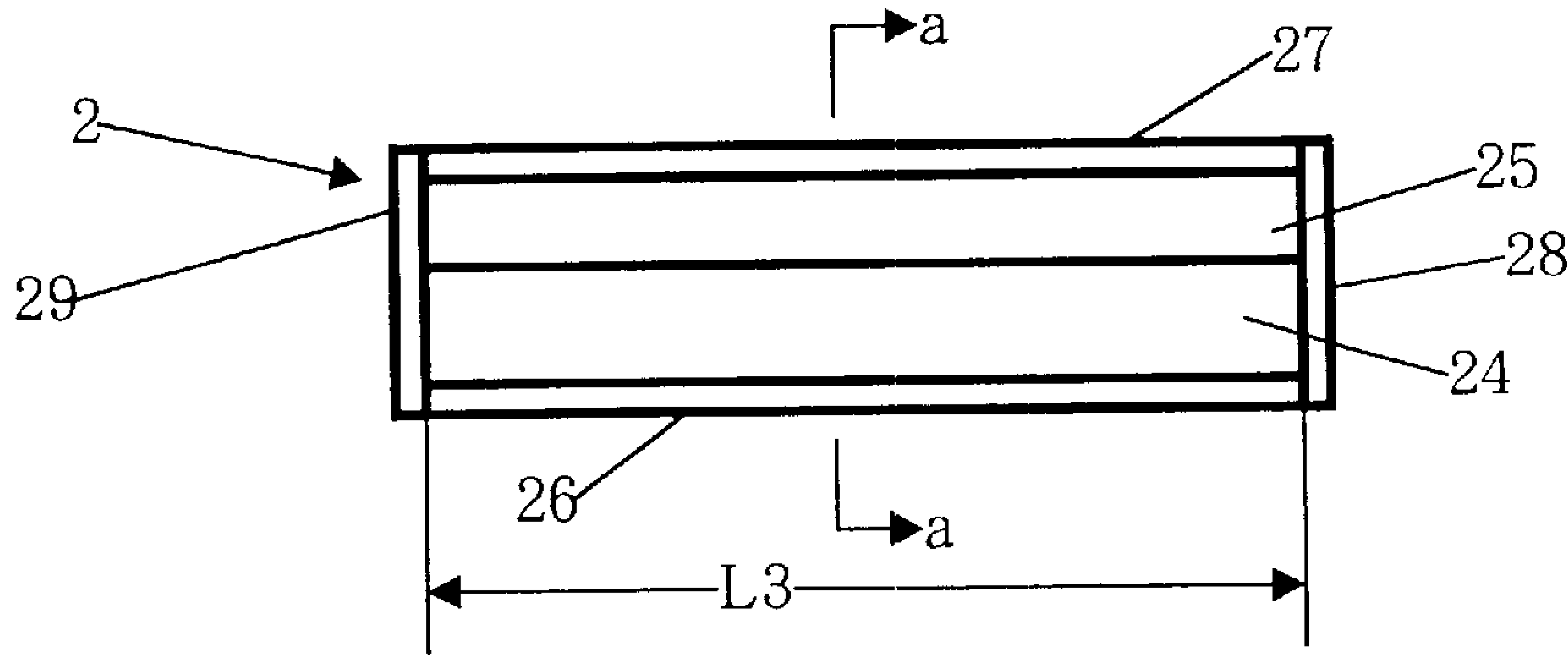

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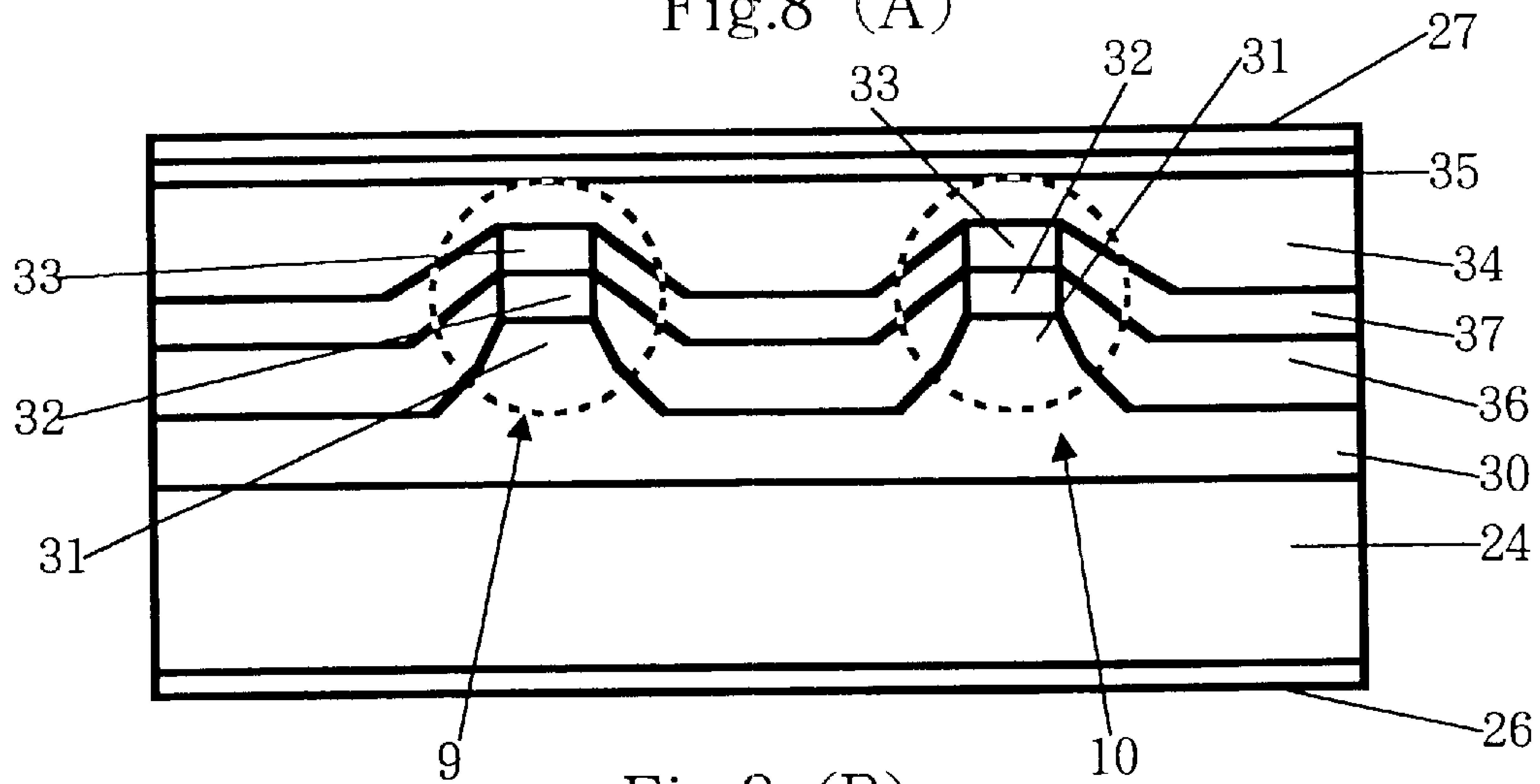

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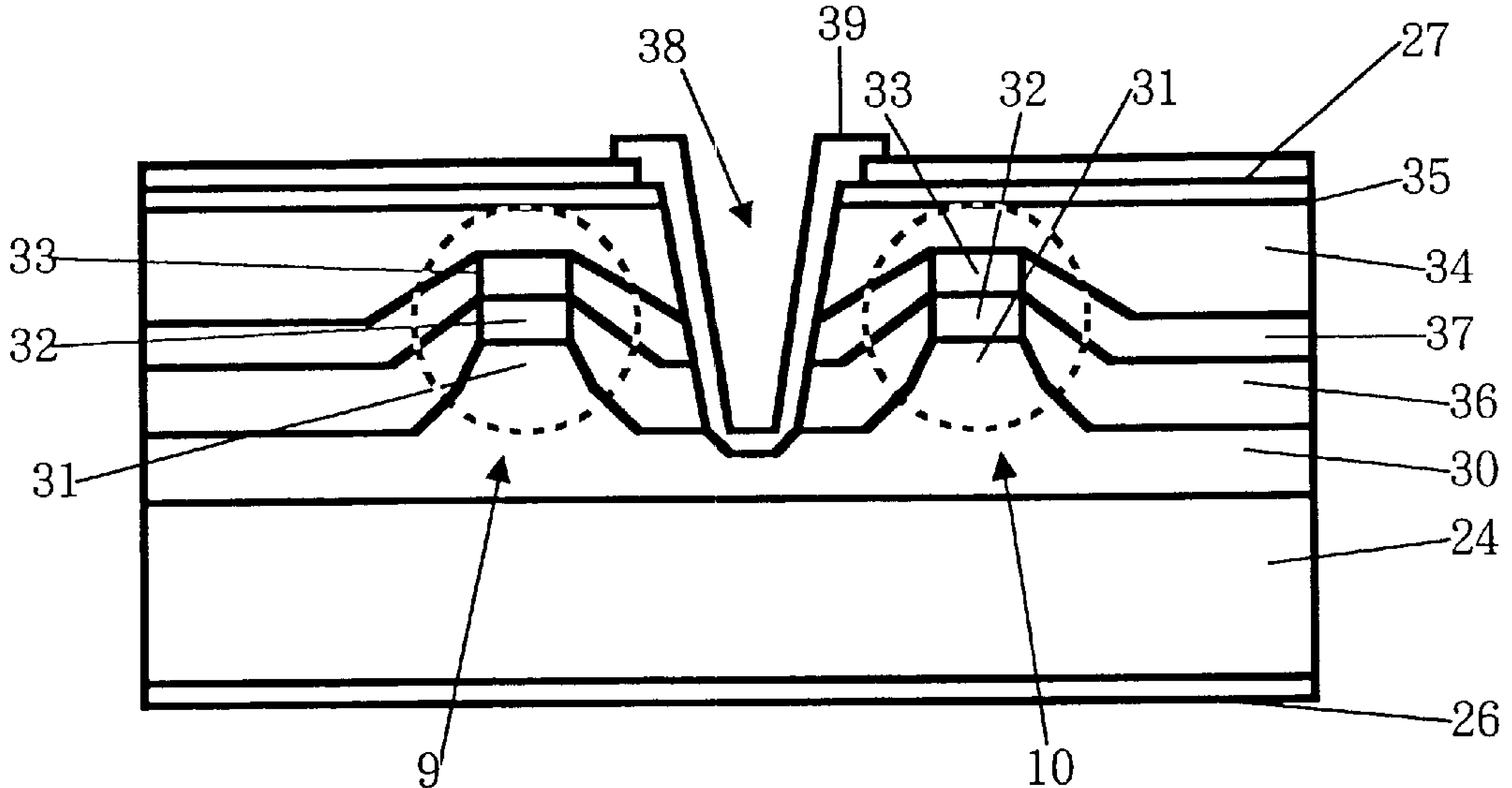

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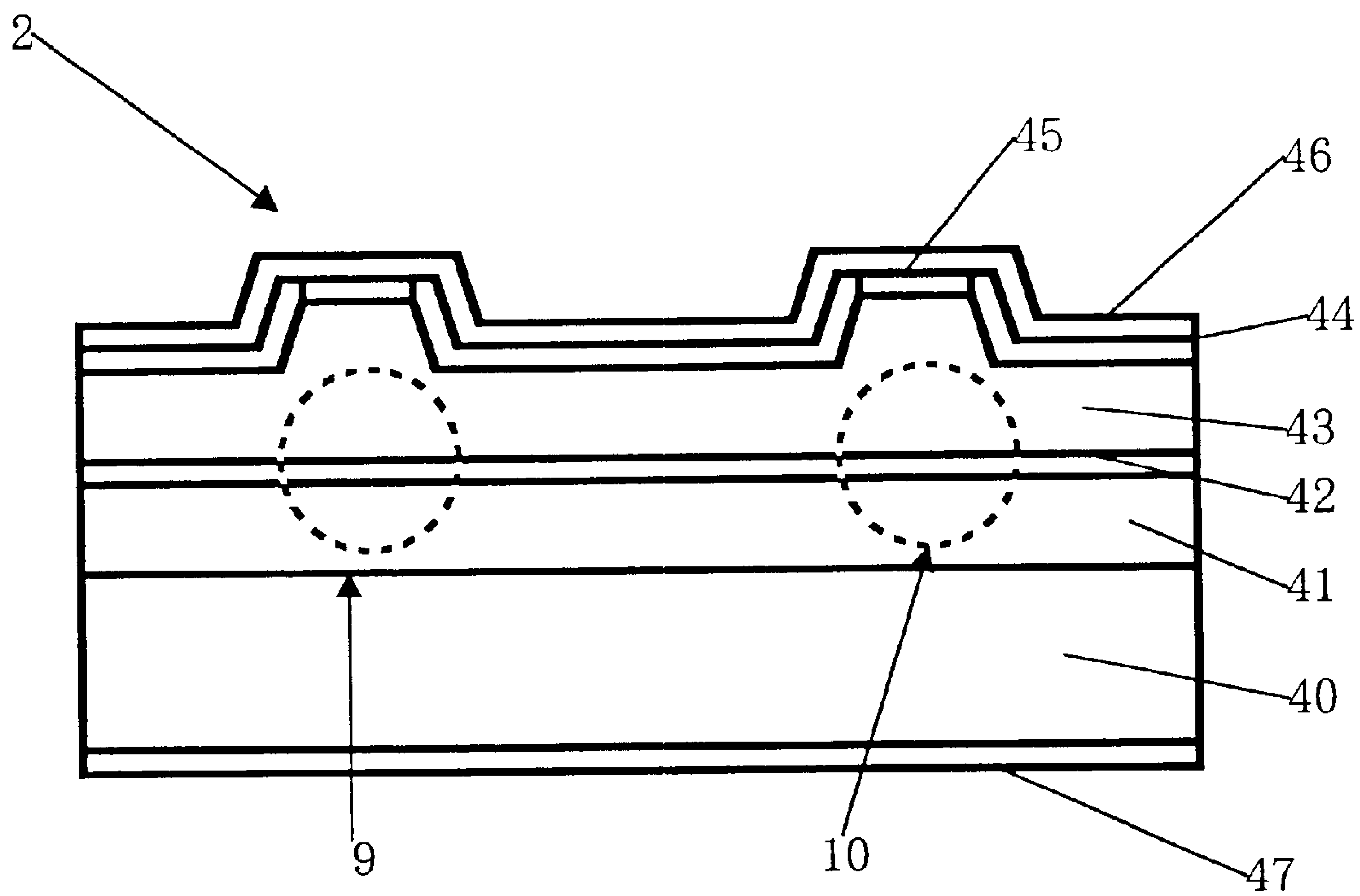


Fig.9

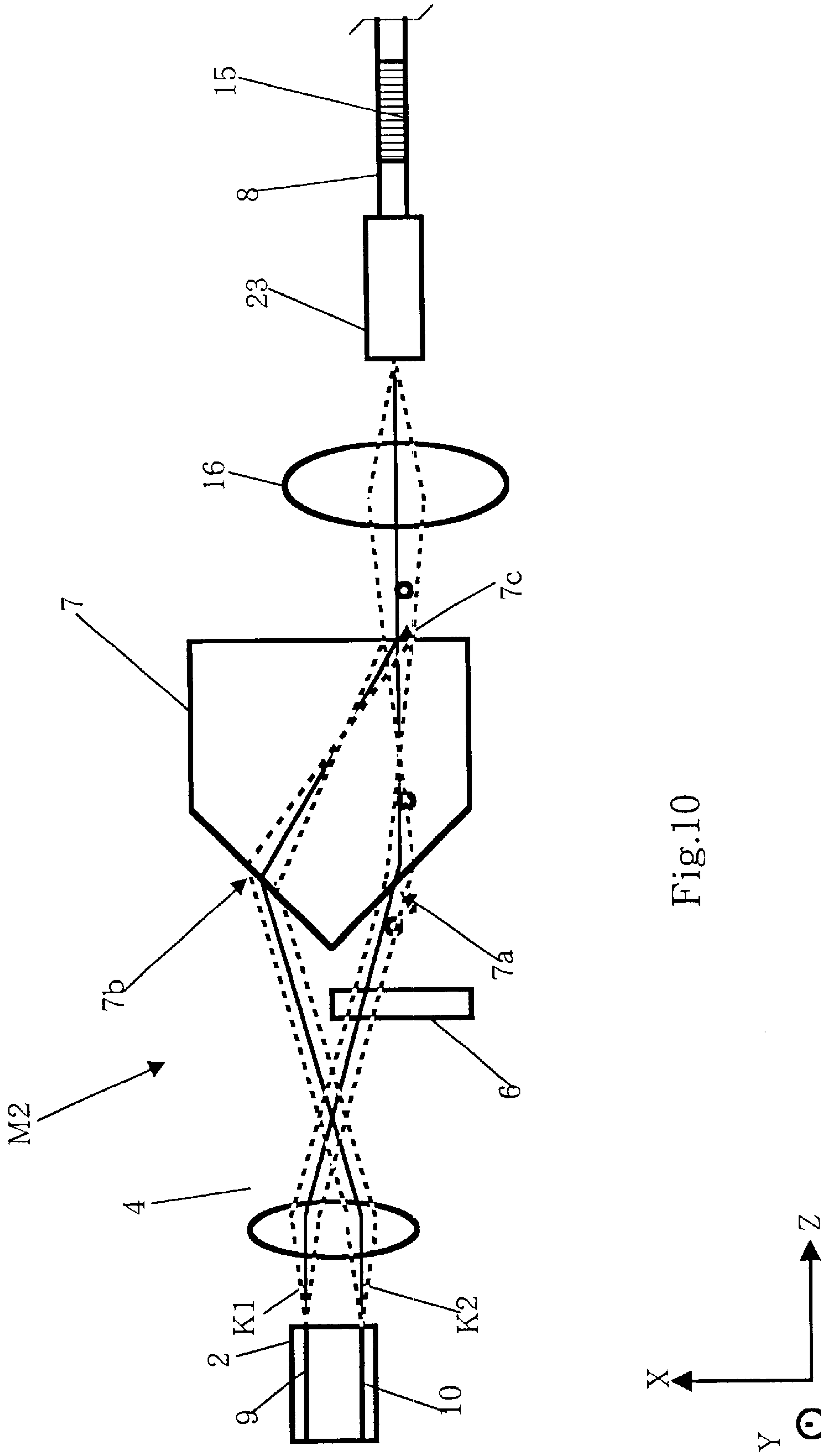


Fig.10

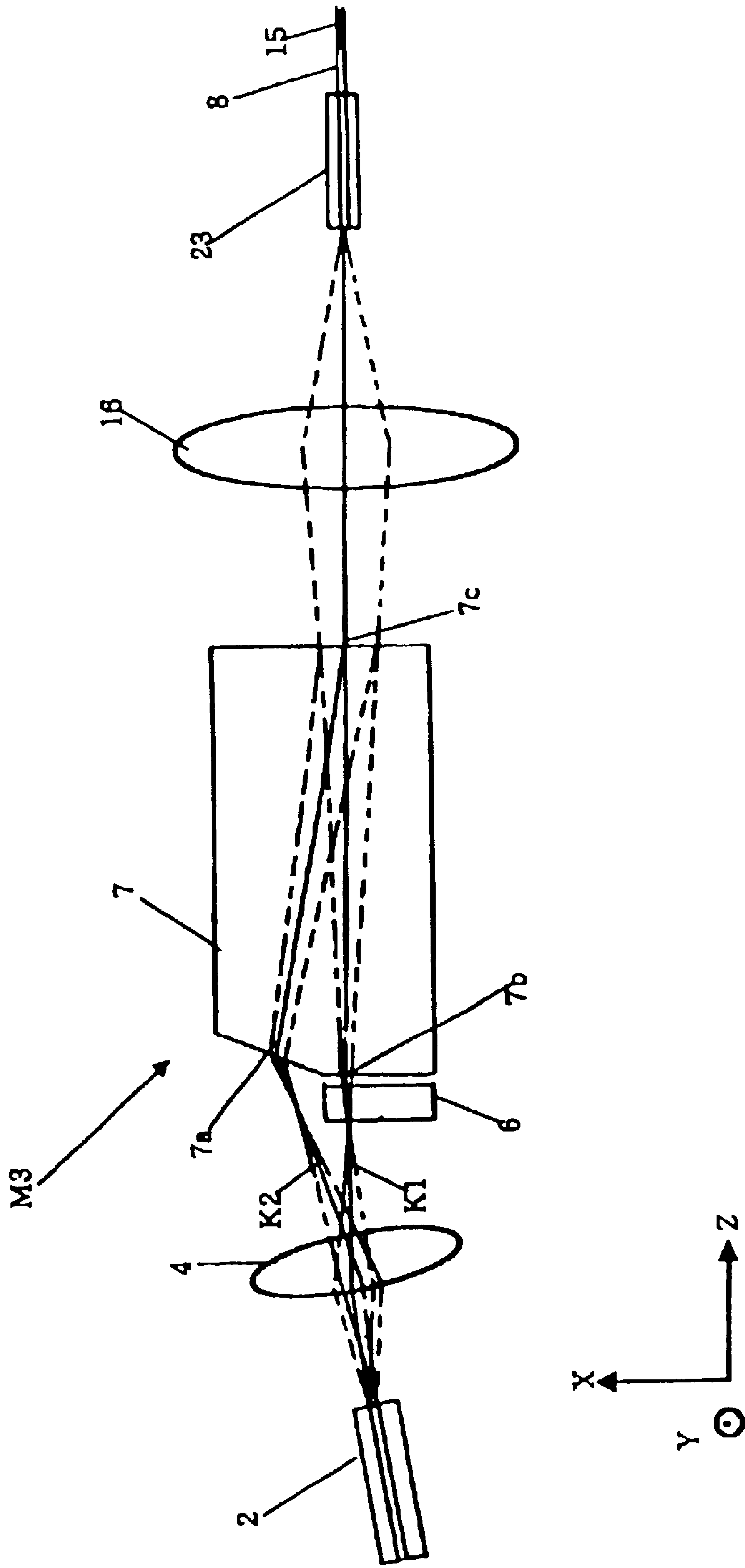


Fig.11

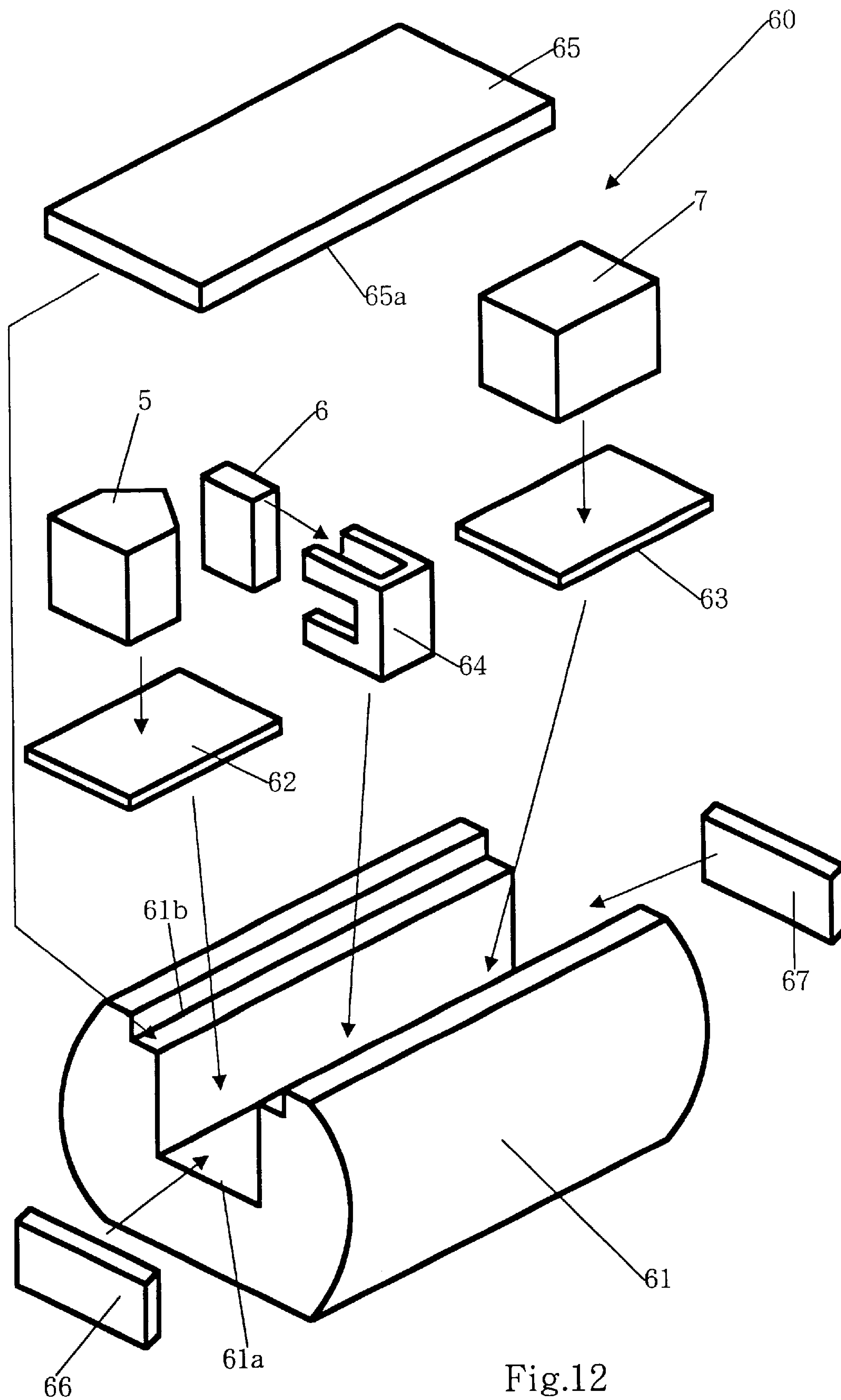


Fig.12

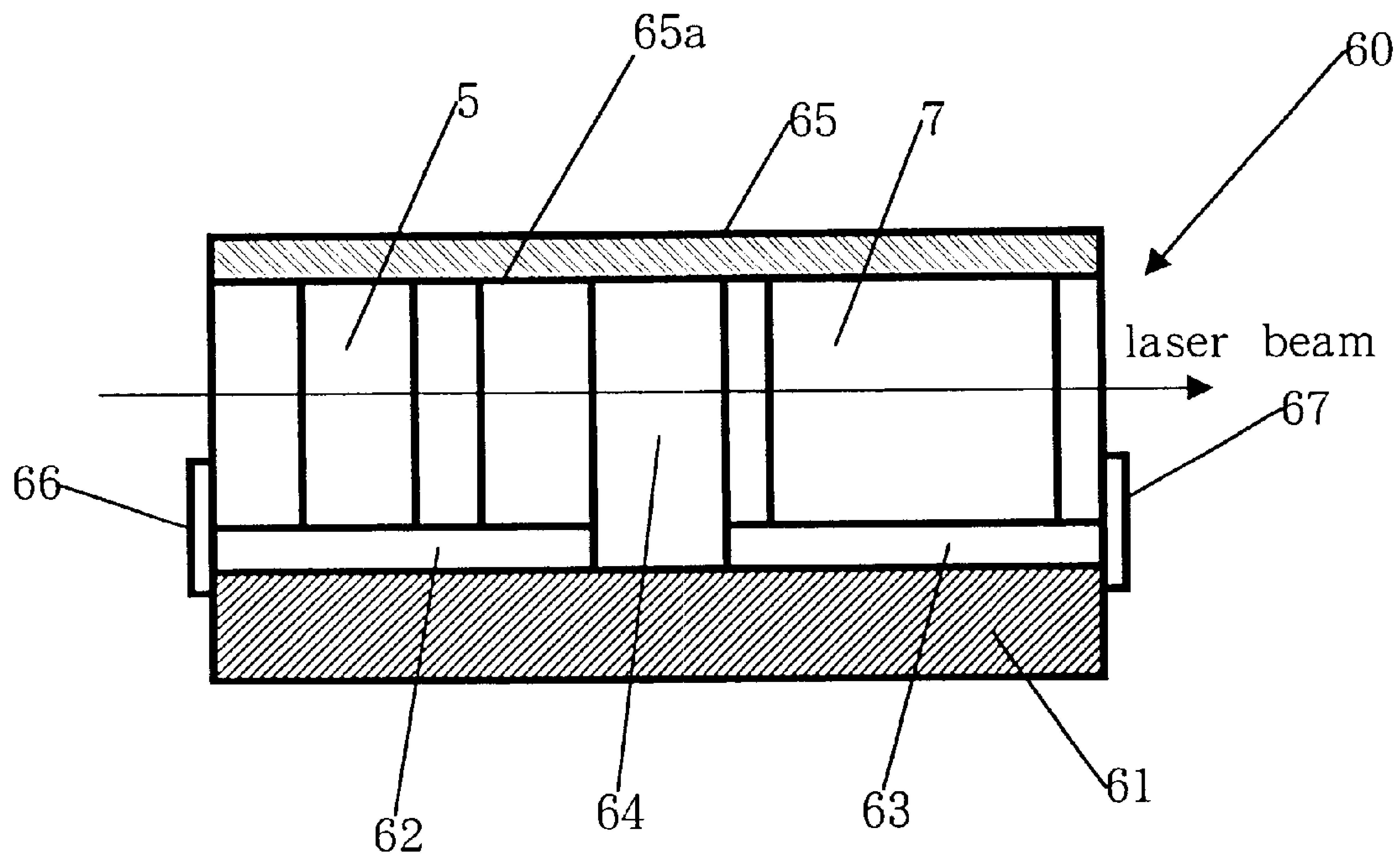


Fig.13

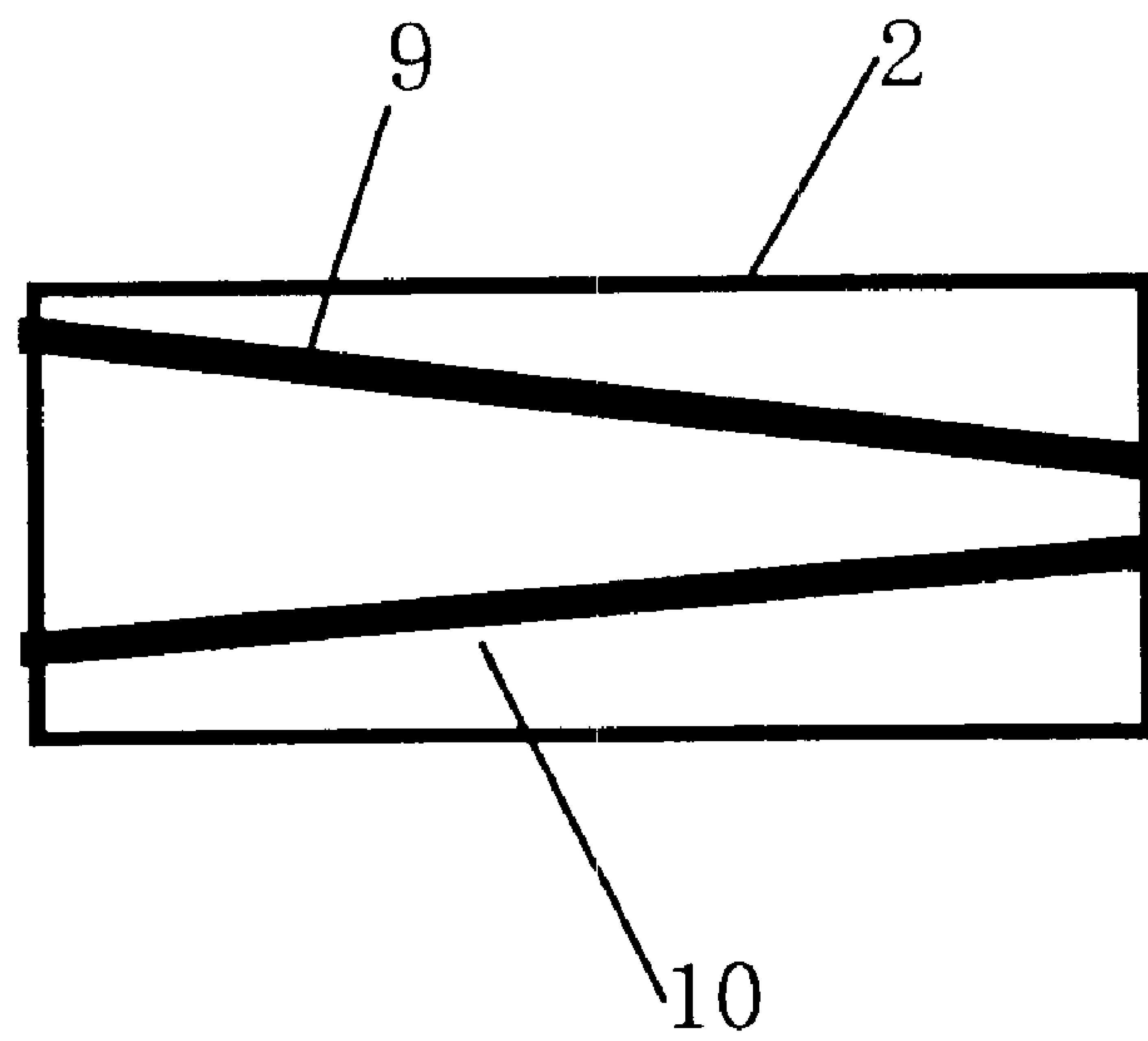
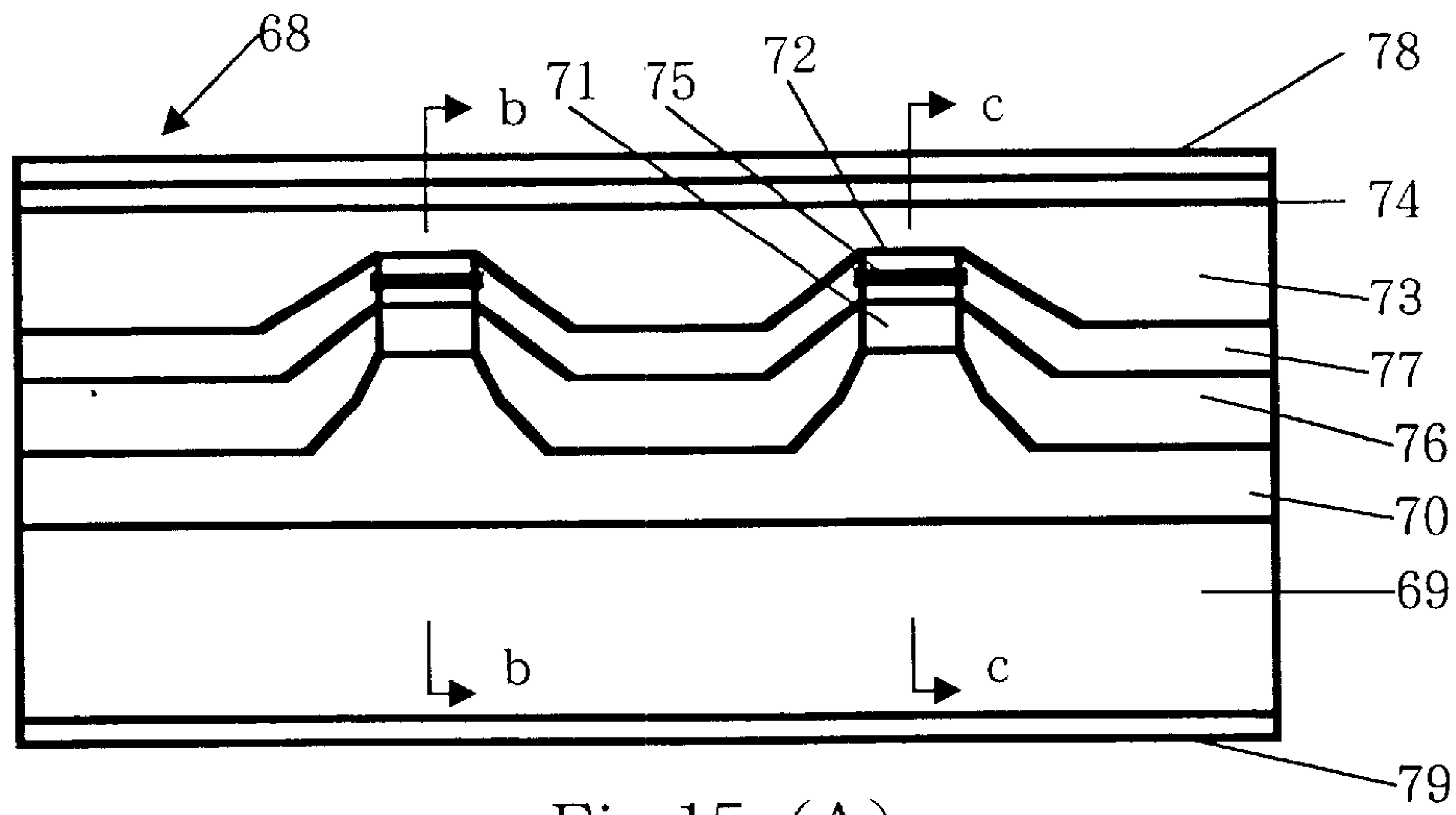


Fig.14



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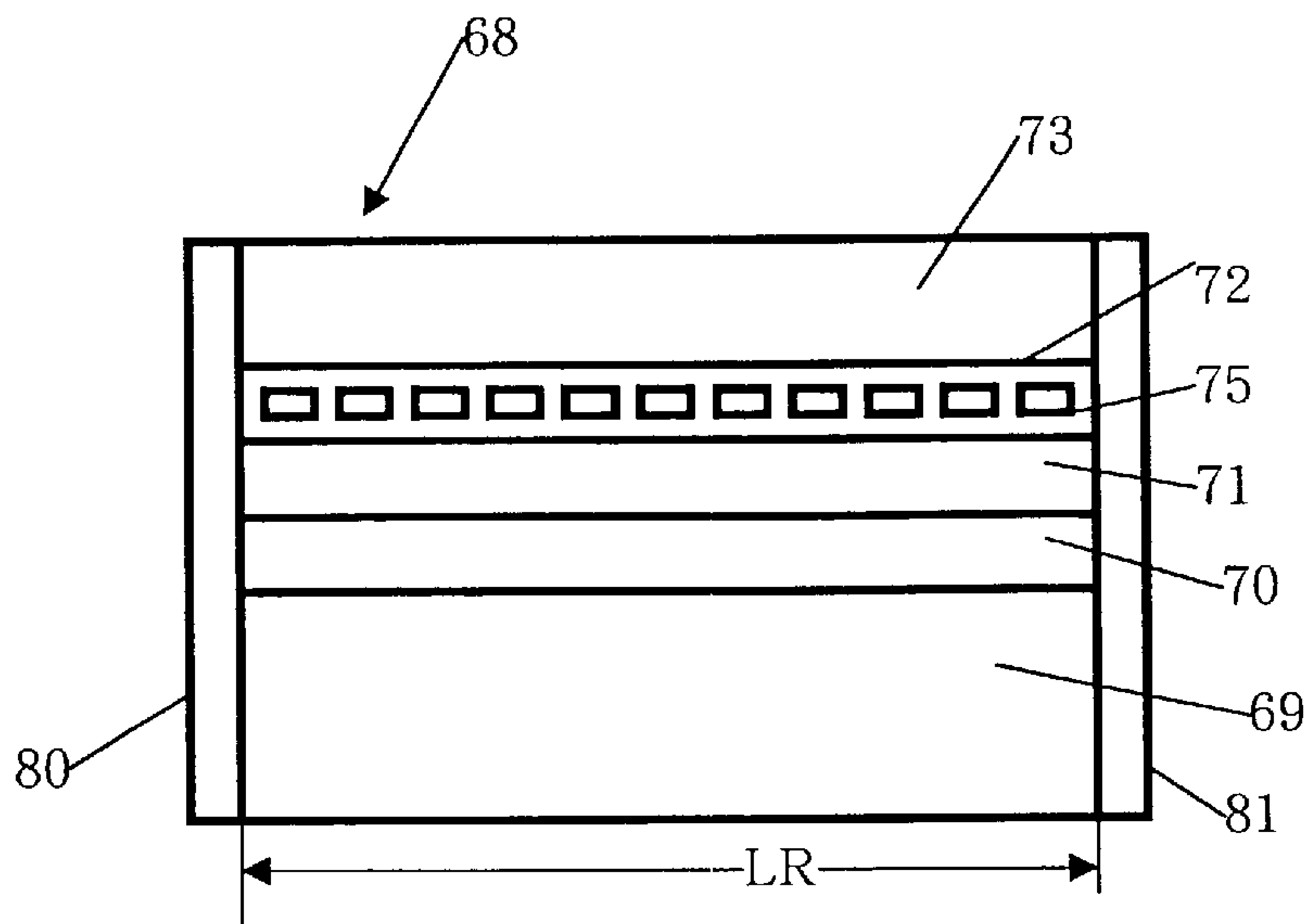

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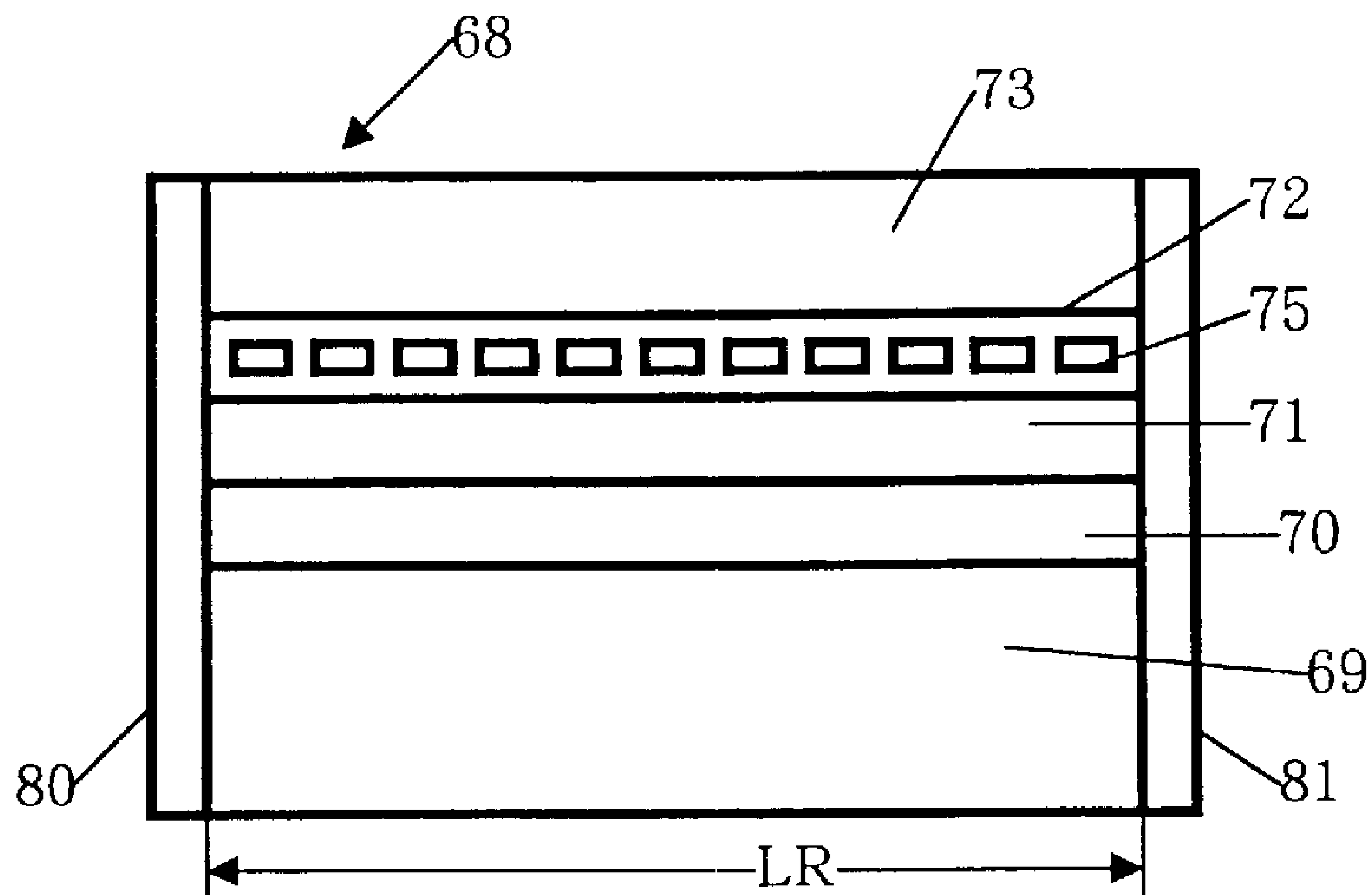

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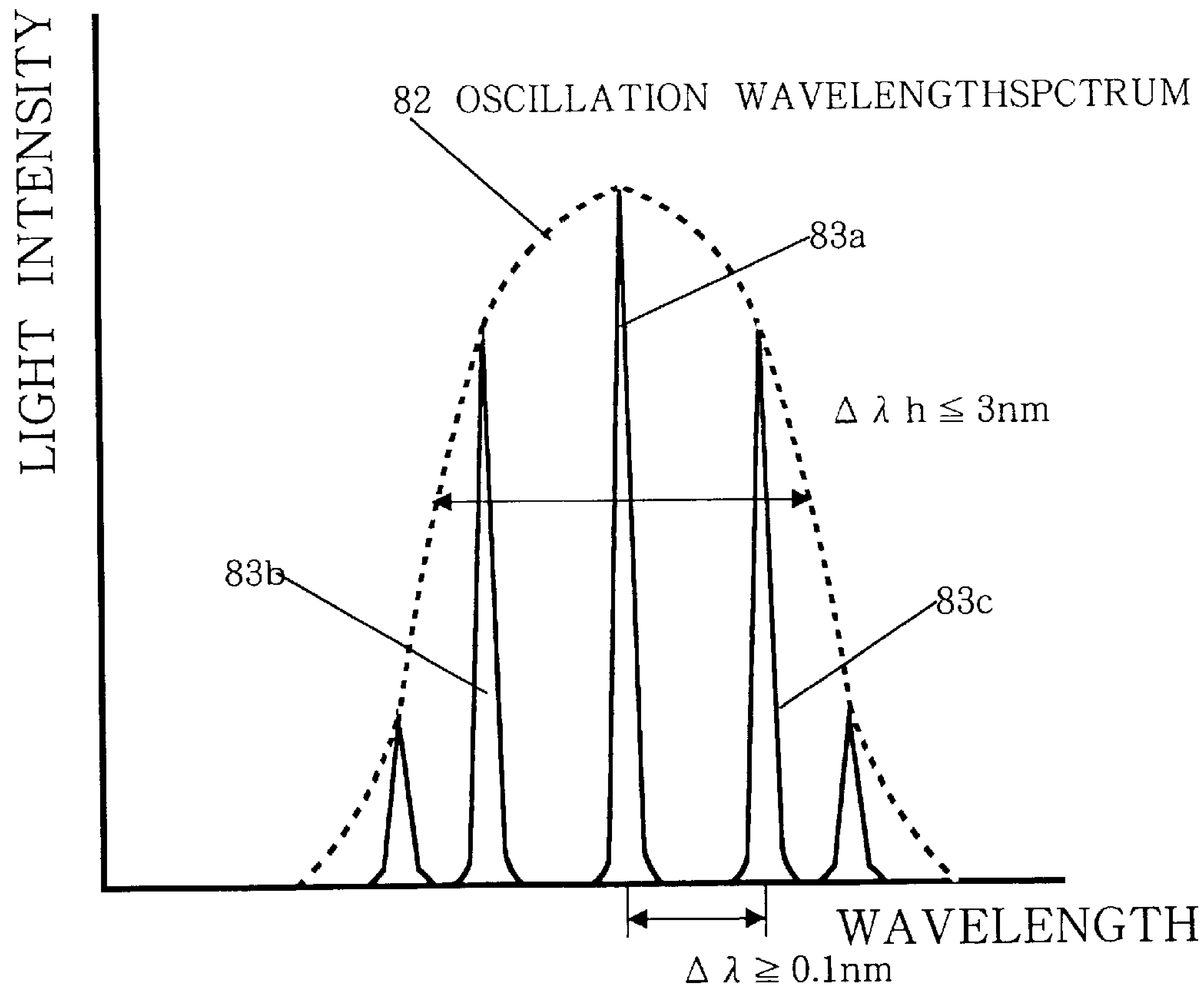

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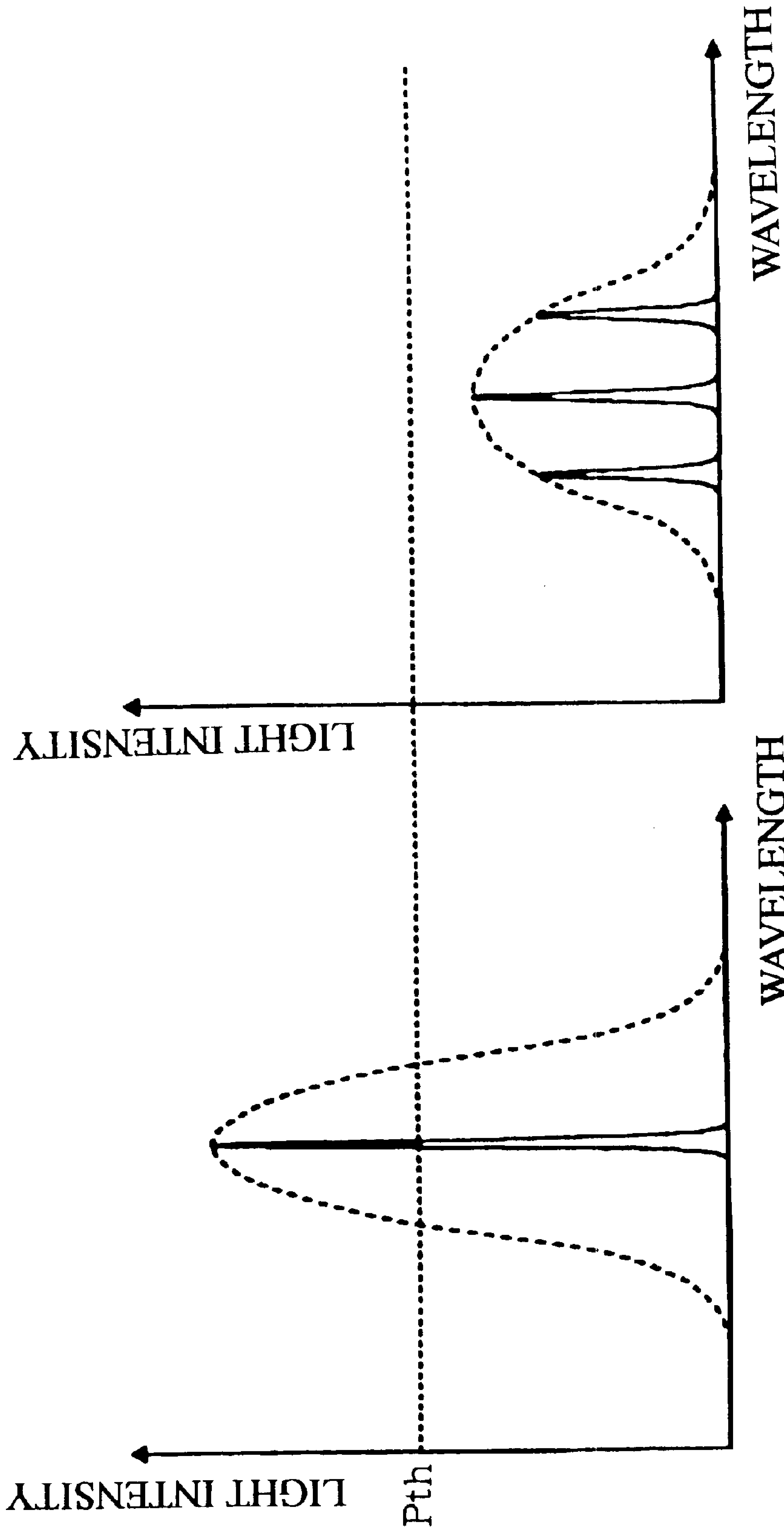

Fig.17 (B)

Fig.17 (A)

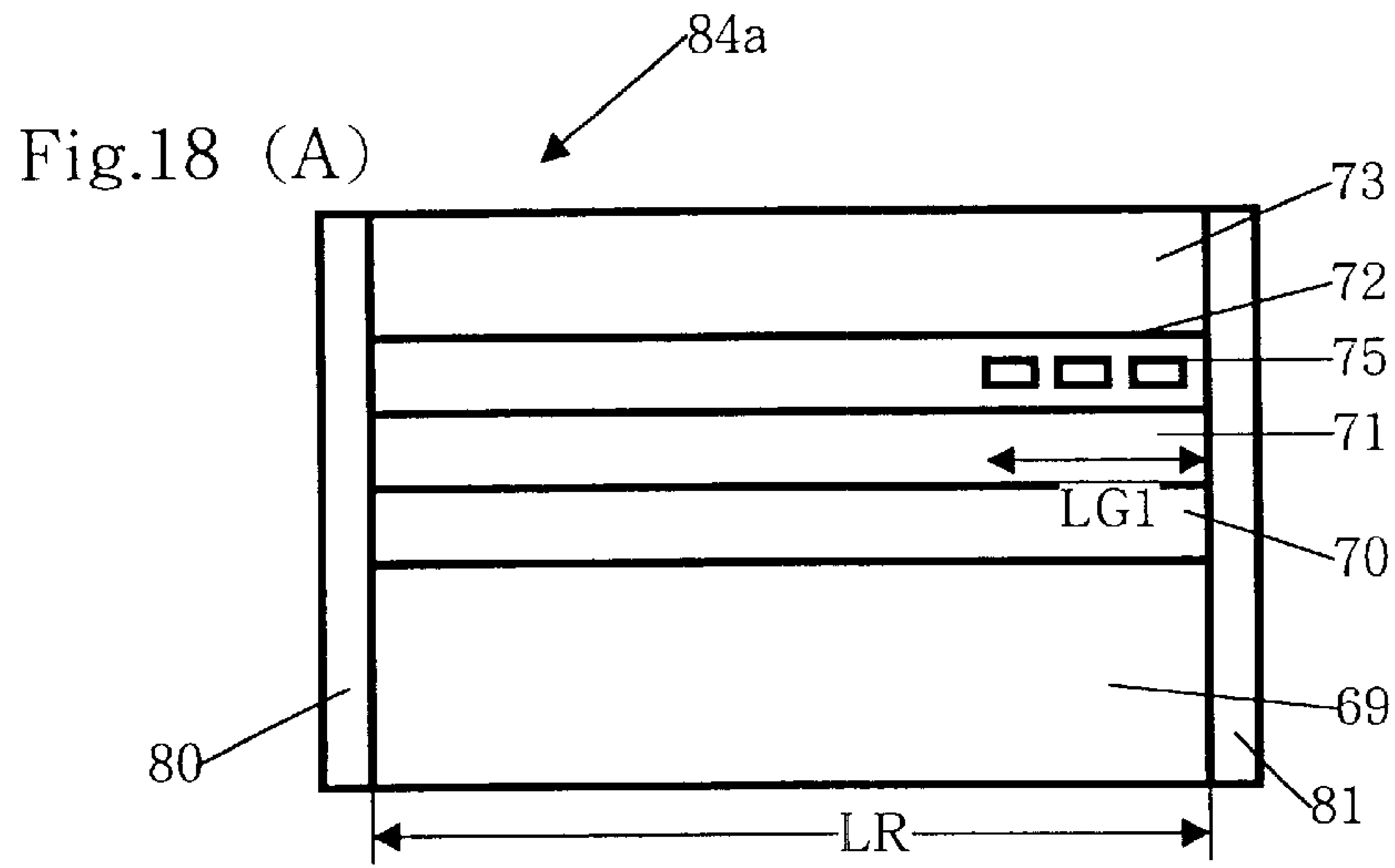
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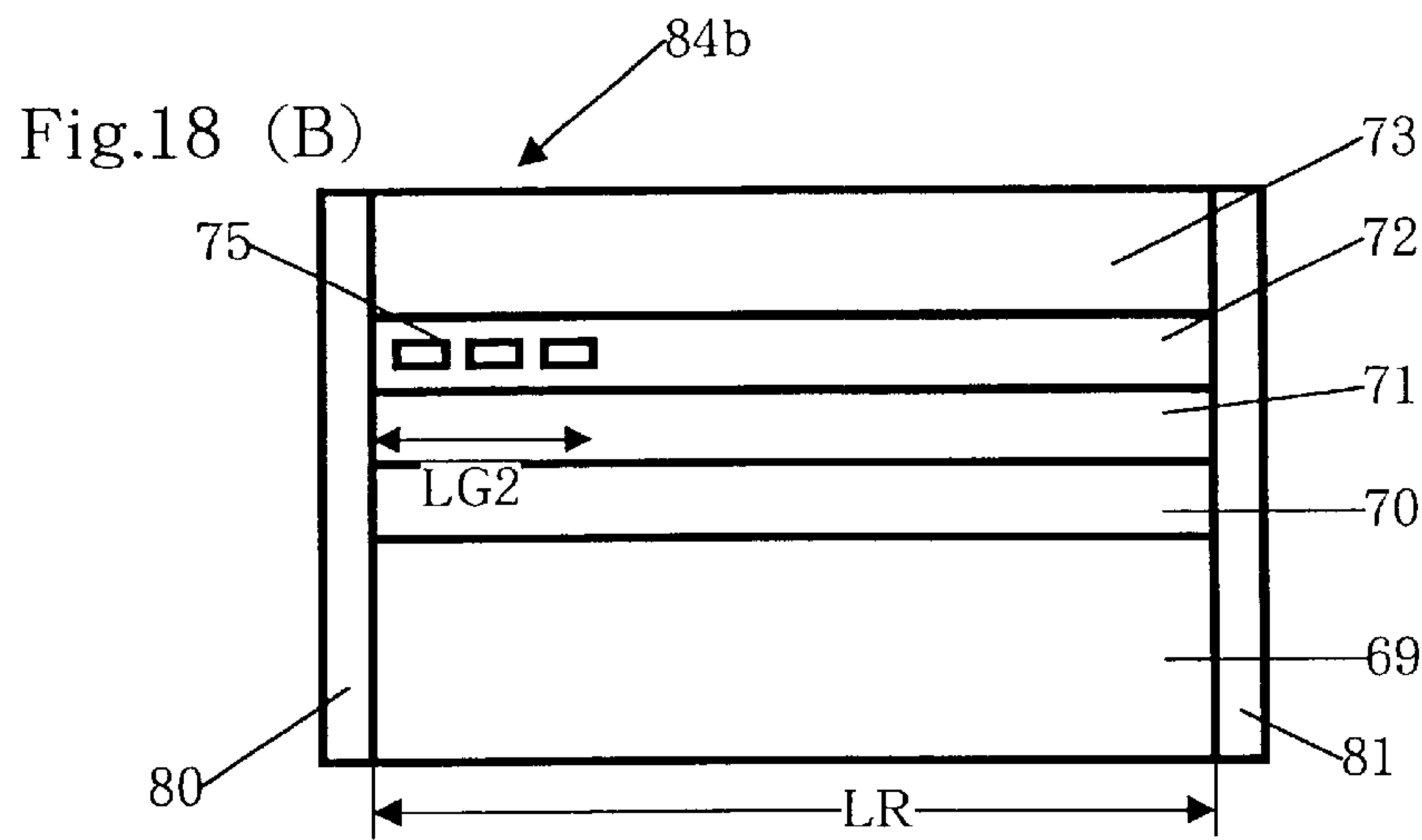
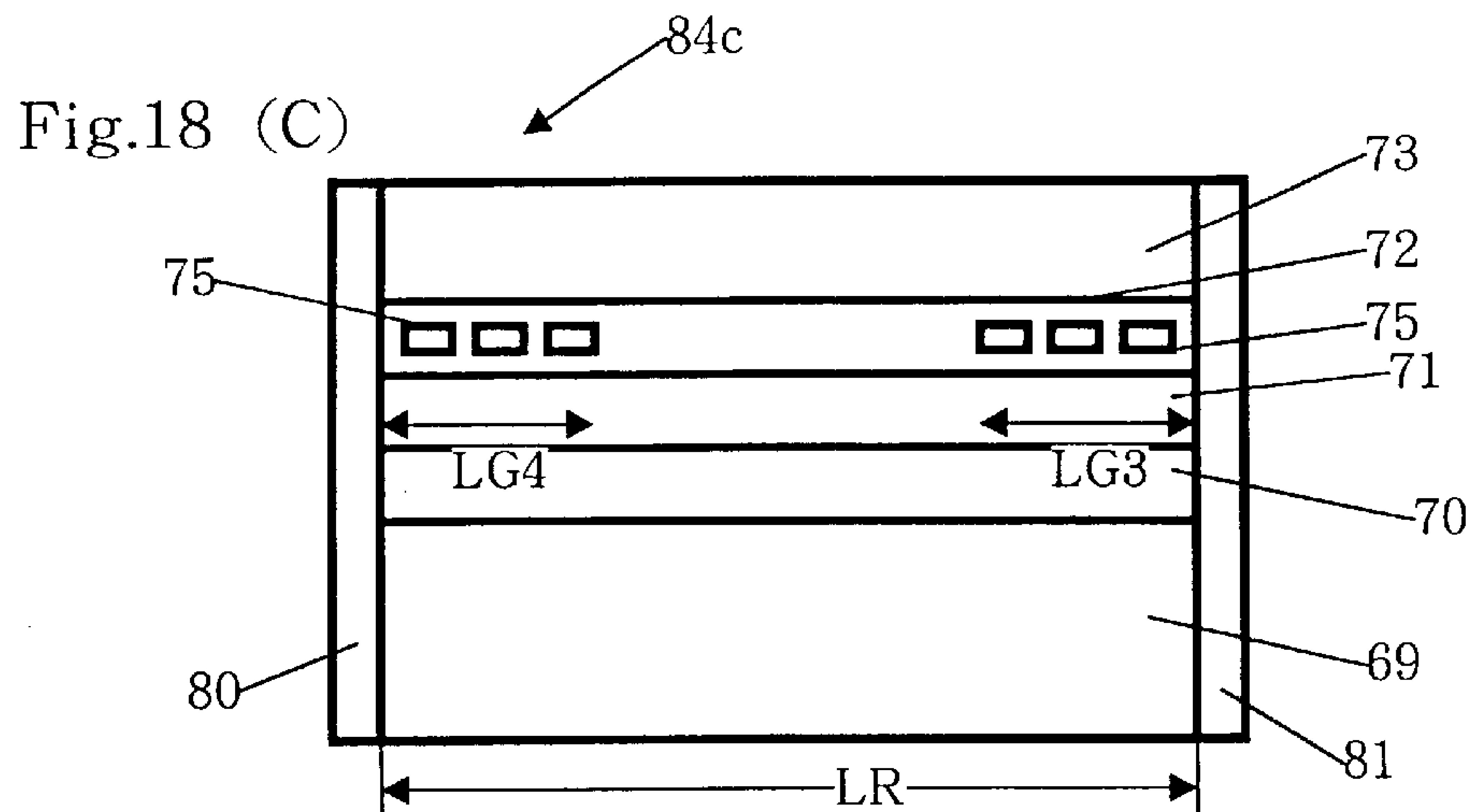
Fig.18 (A)
73
72
75
71
LG1
70
69
80
81
LR


84b
Fig.18 (B)
73
75
72
71
LG2
70
69
80
81
LR


84c
Fig.18 (C)
73
75
72
75
71
LG4
LG3
70
69
80
81
LR

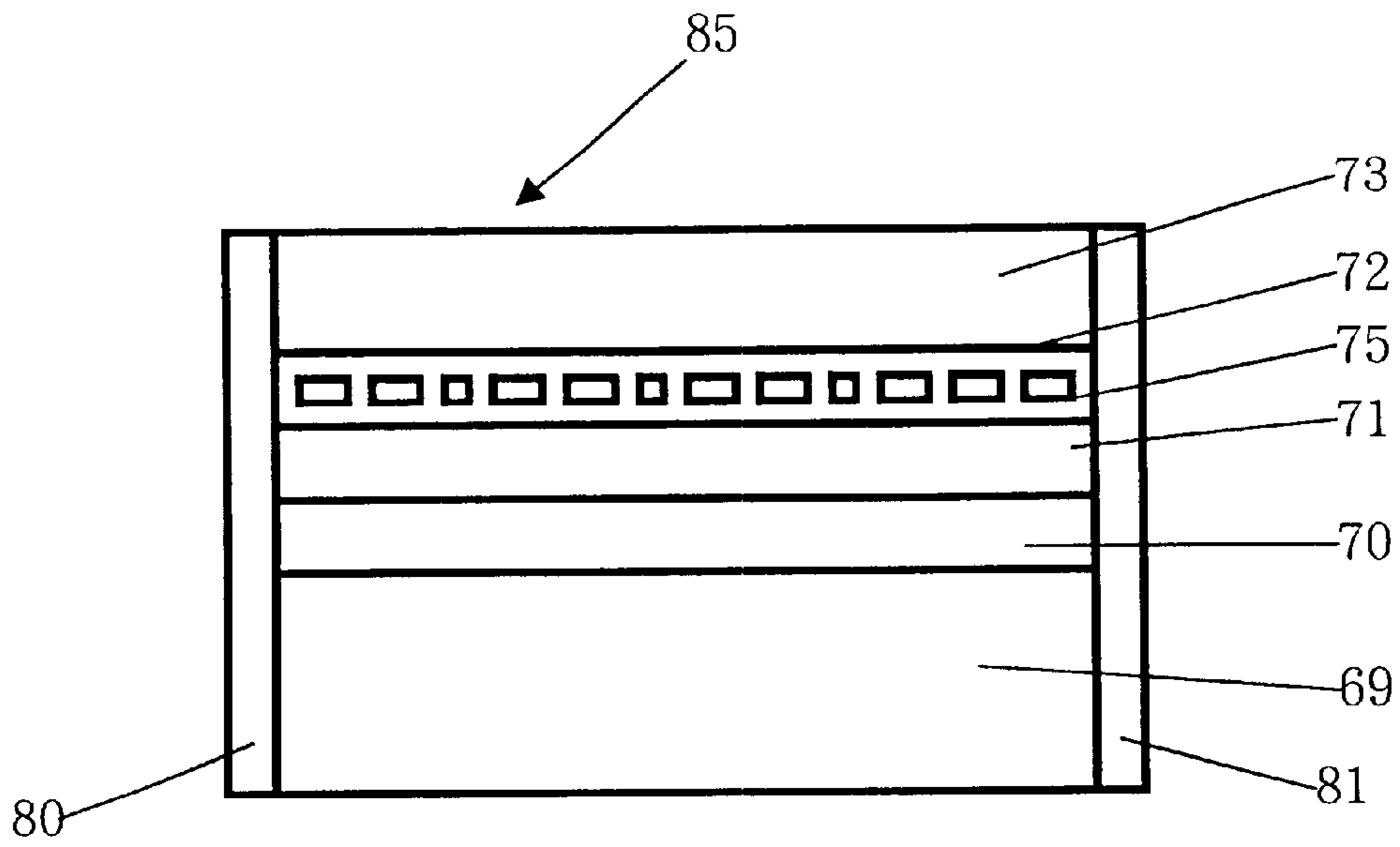
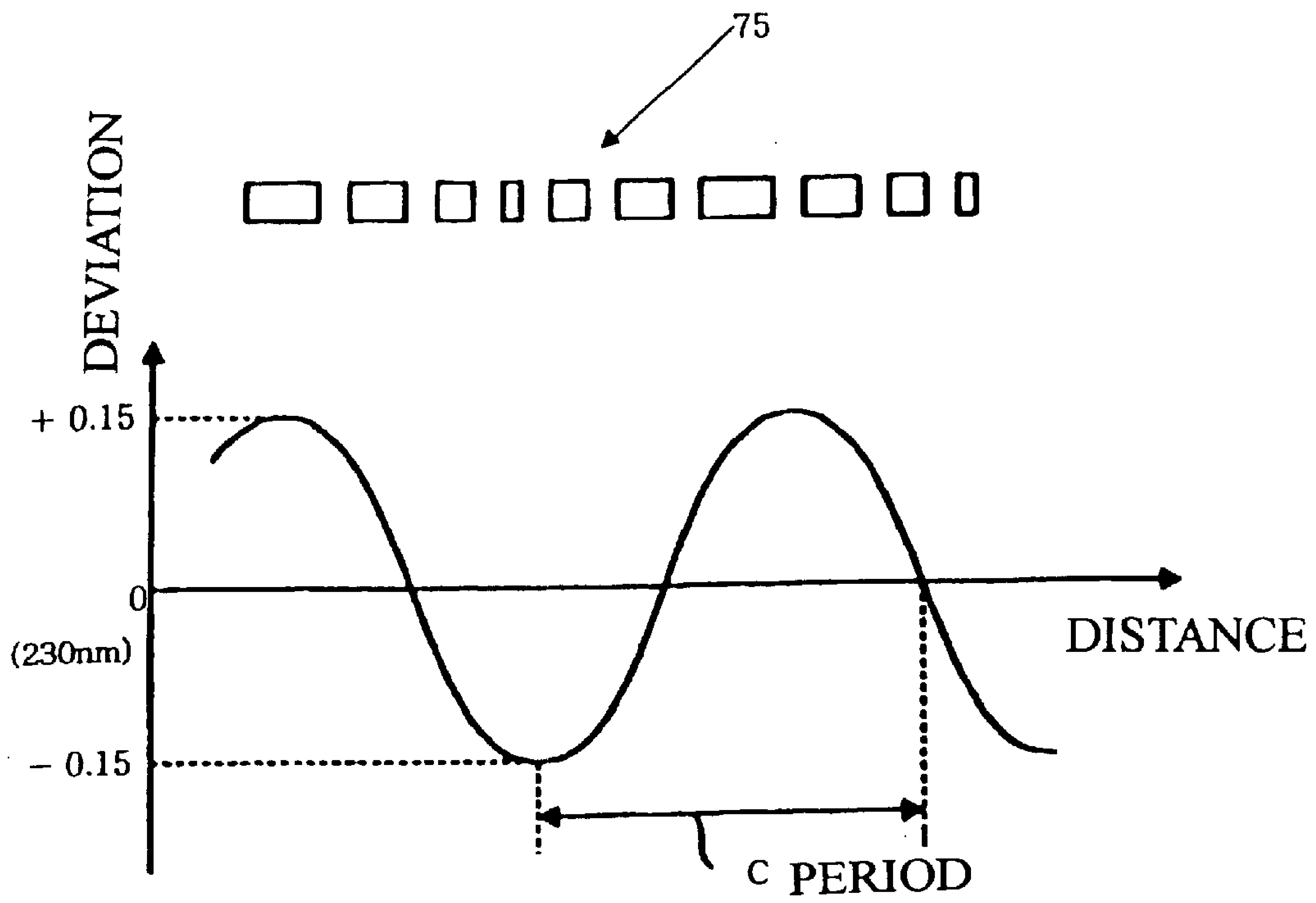


Fig.19

Fig. 20



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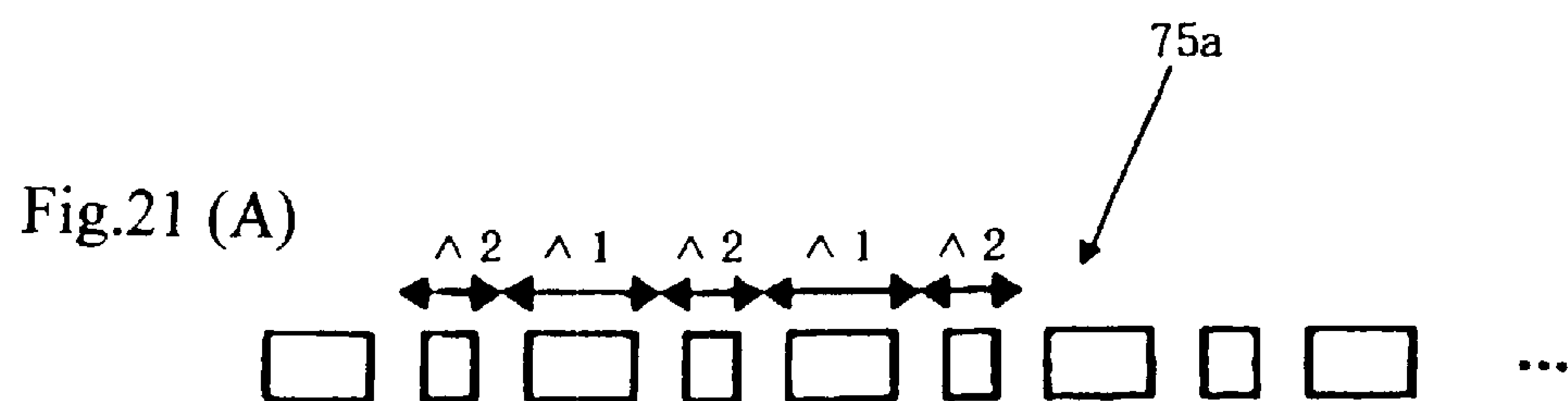

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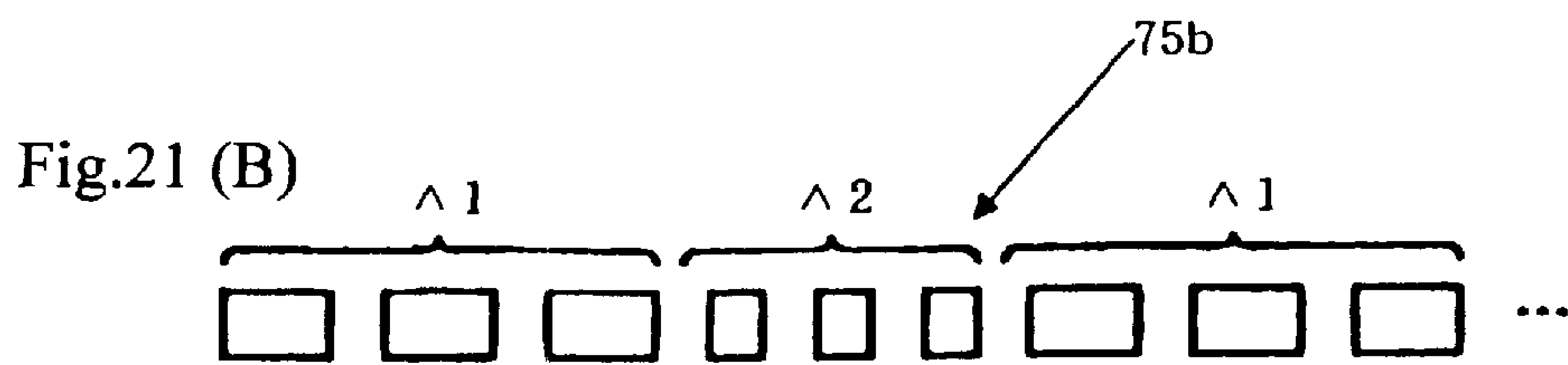

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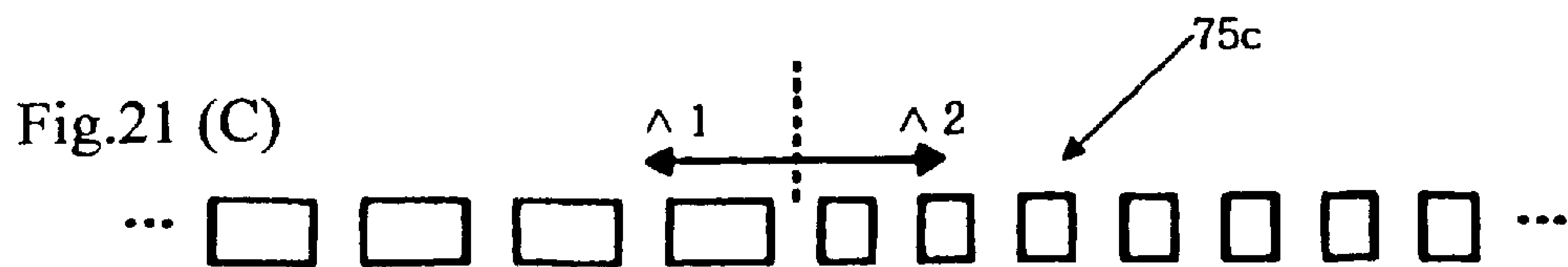

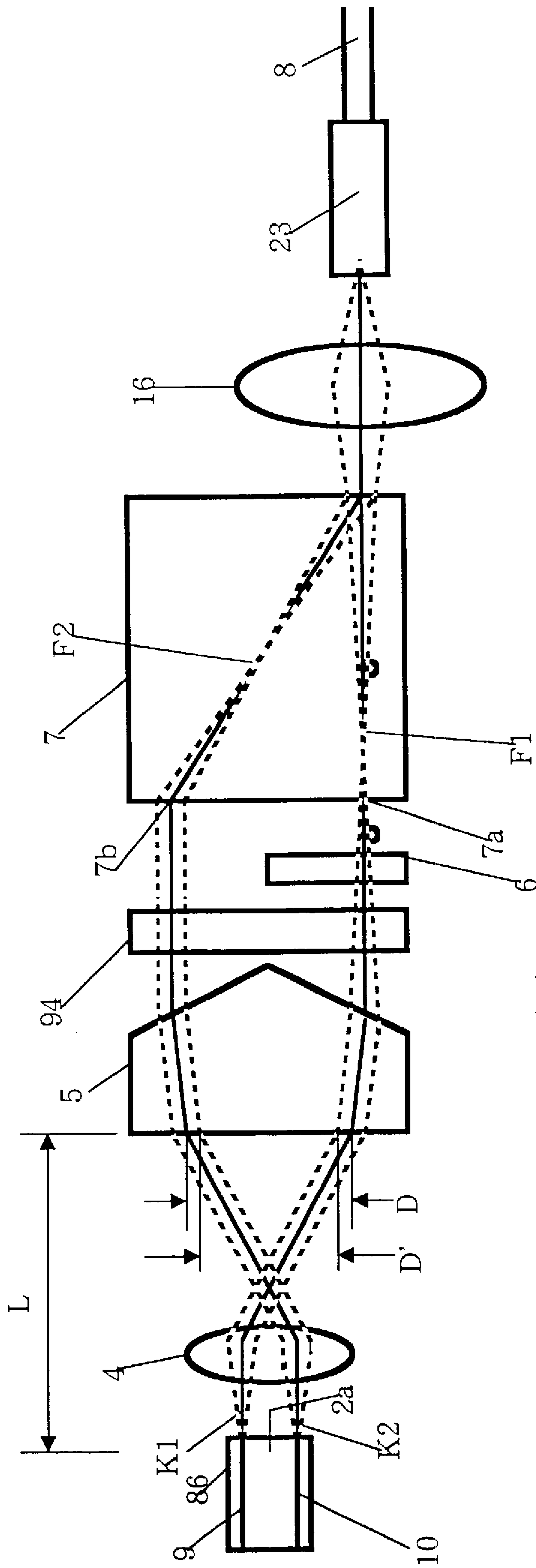

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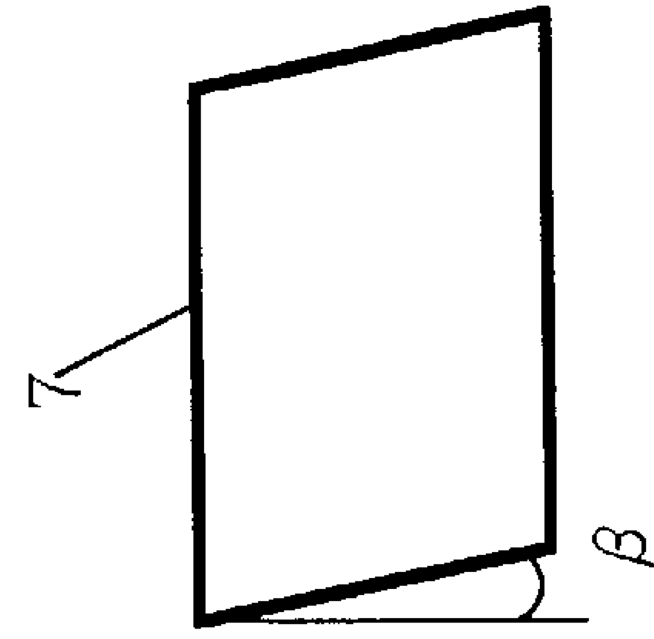

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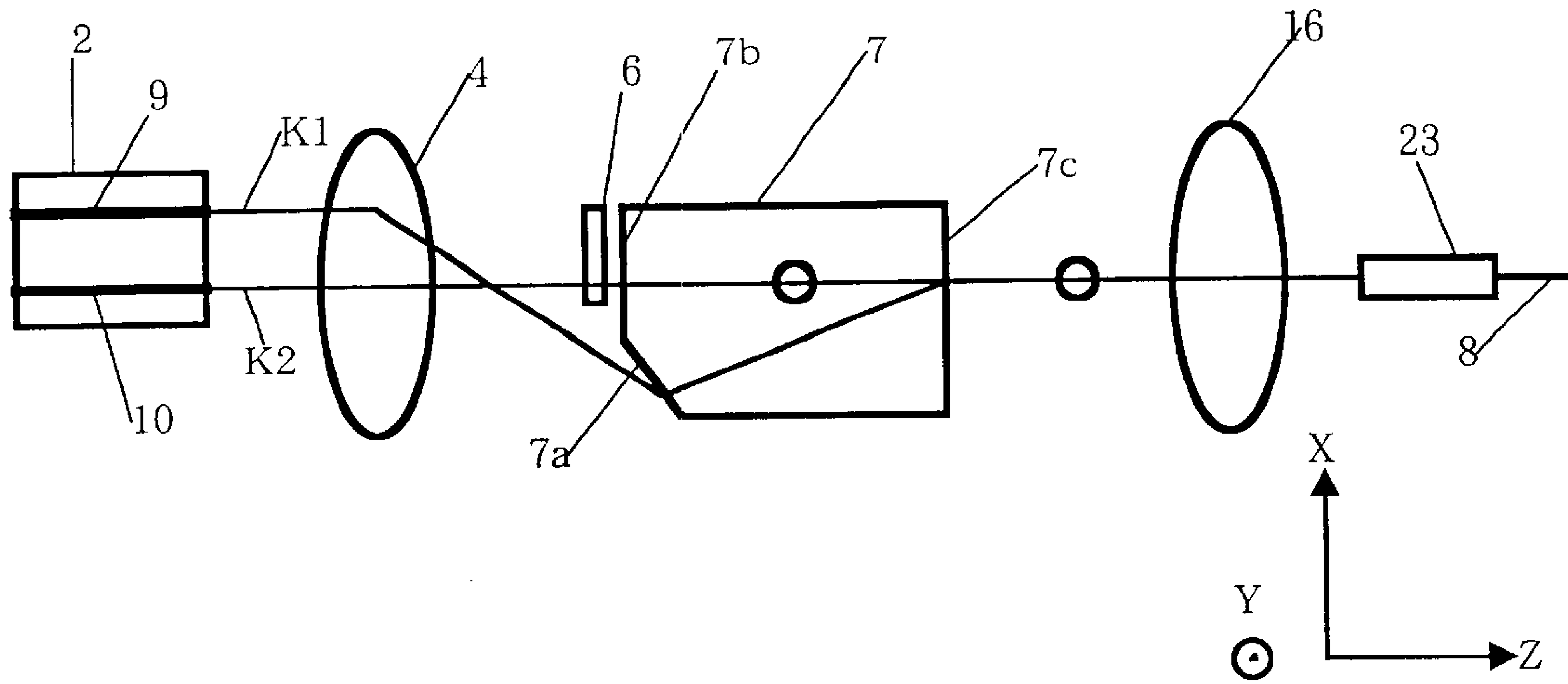

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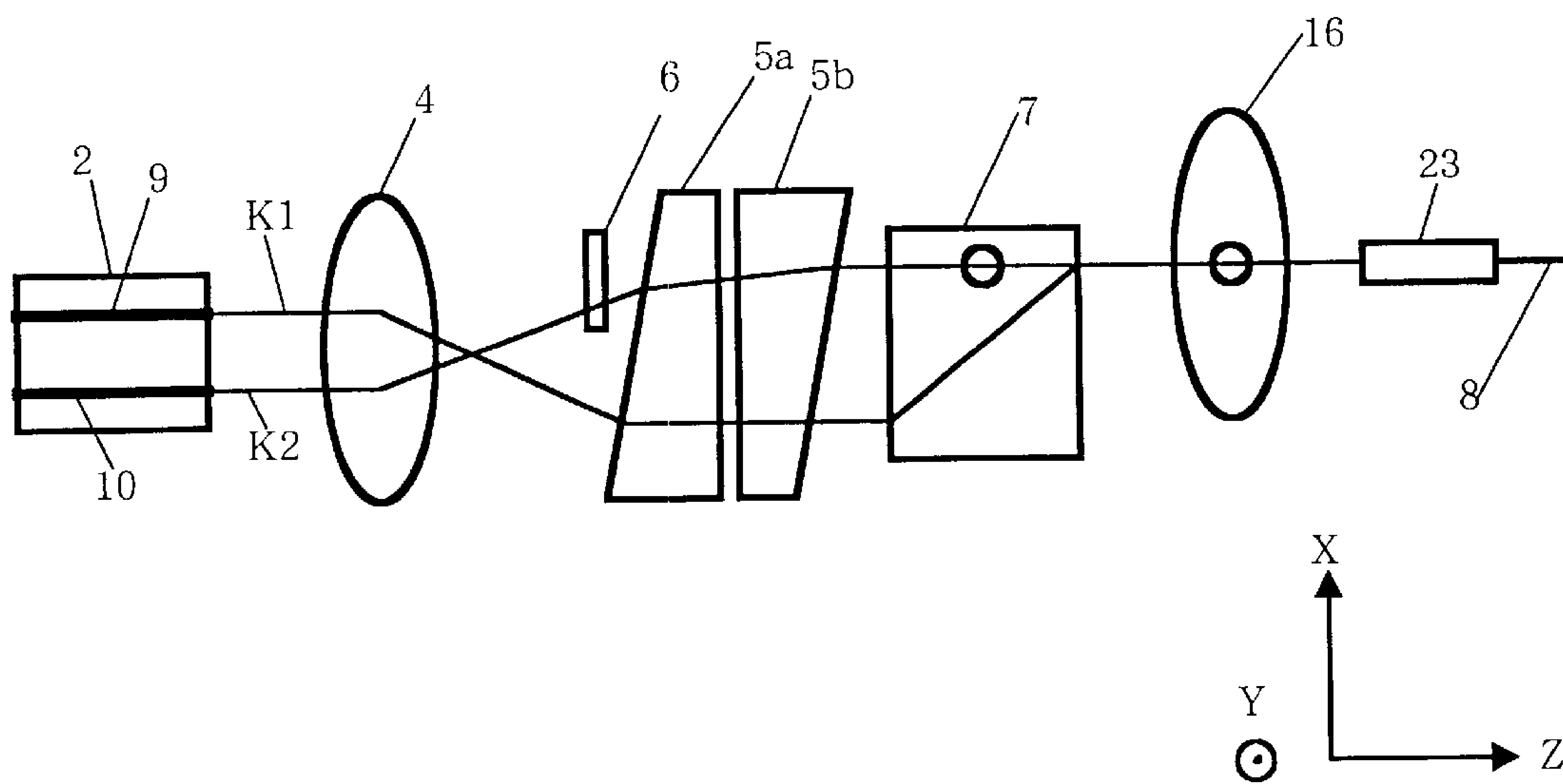

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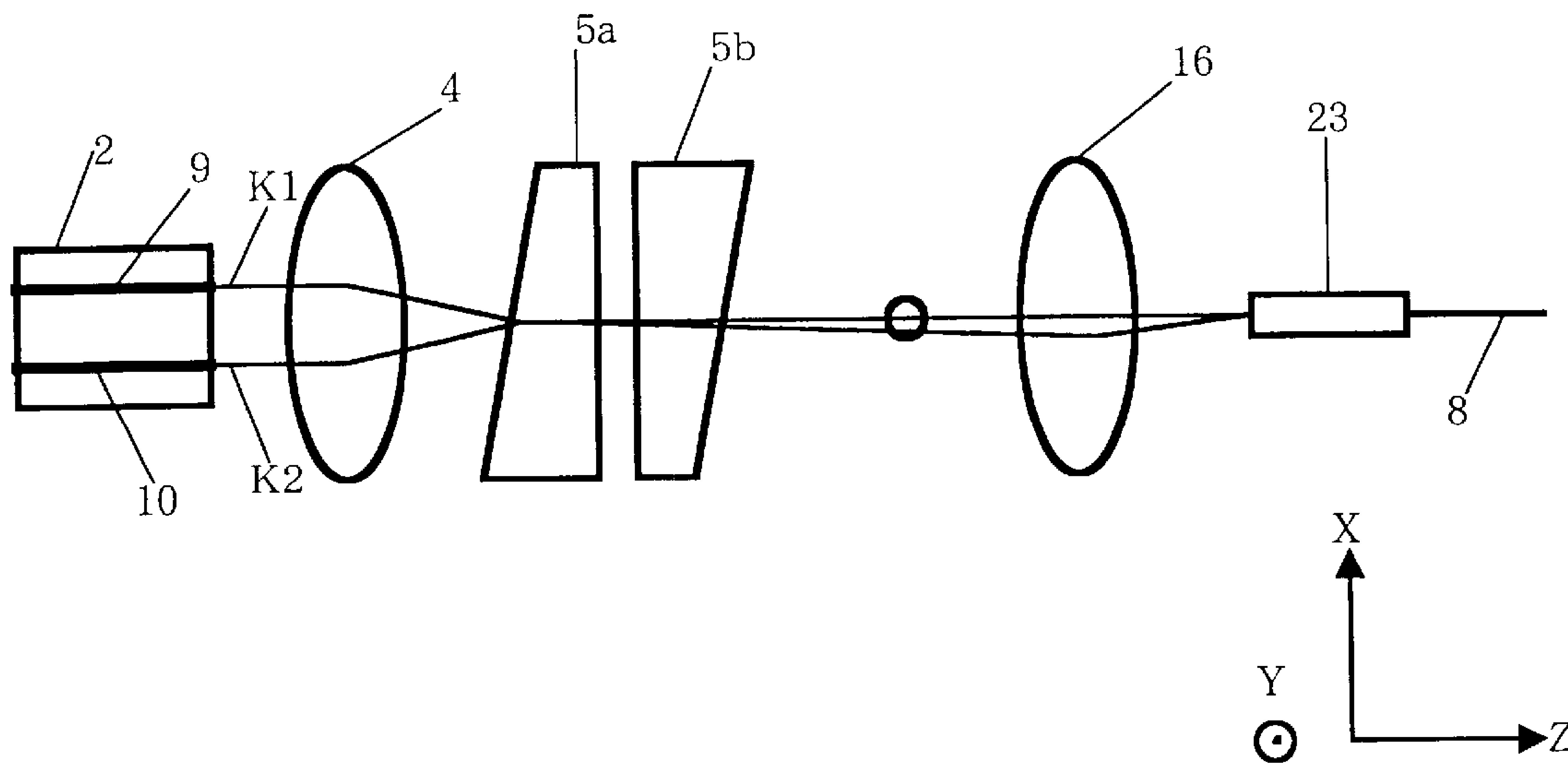

Fig.25

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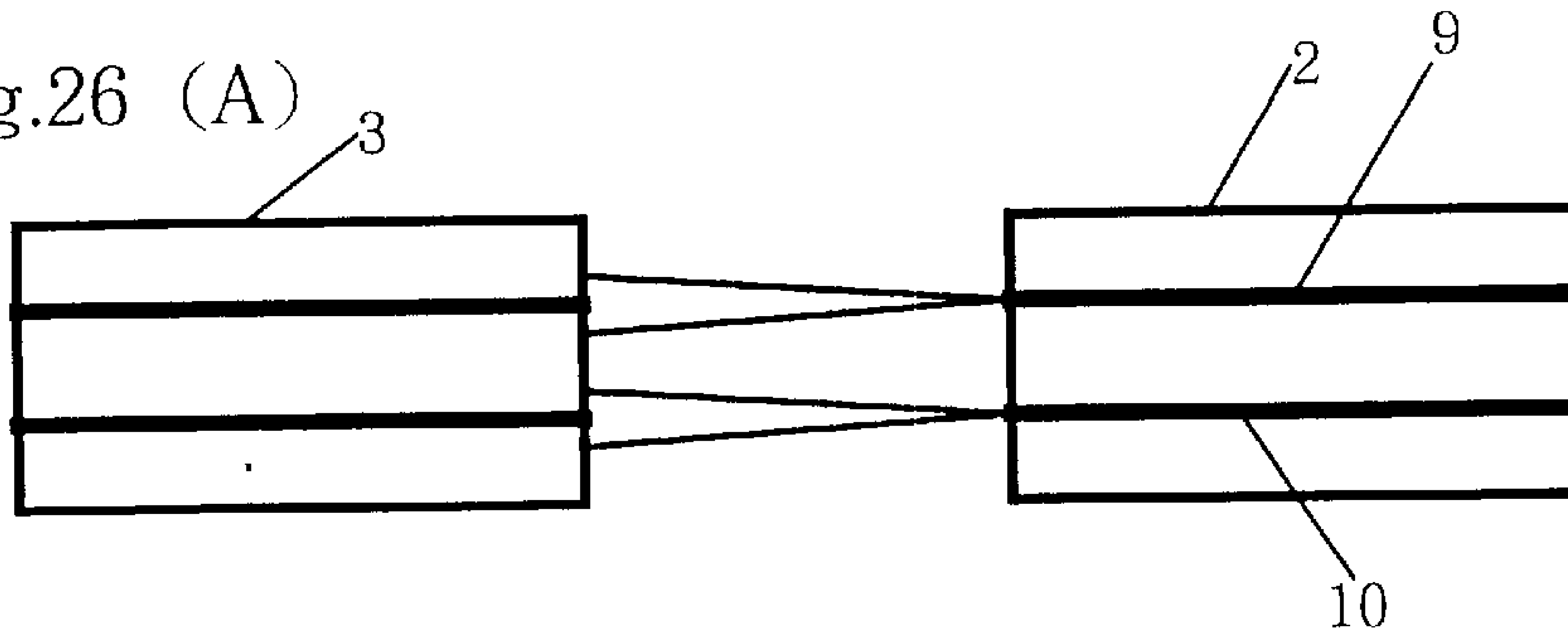

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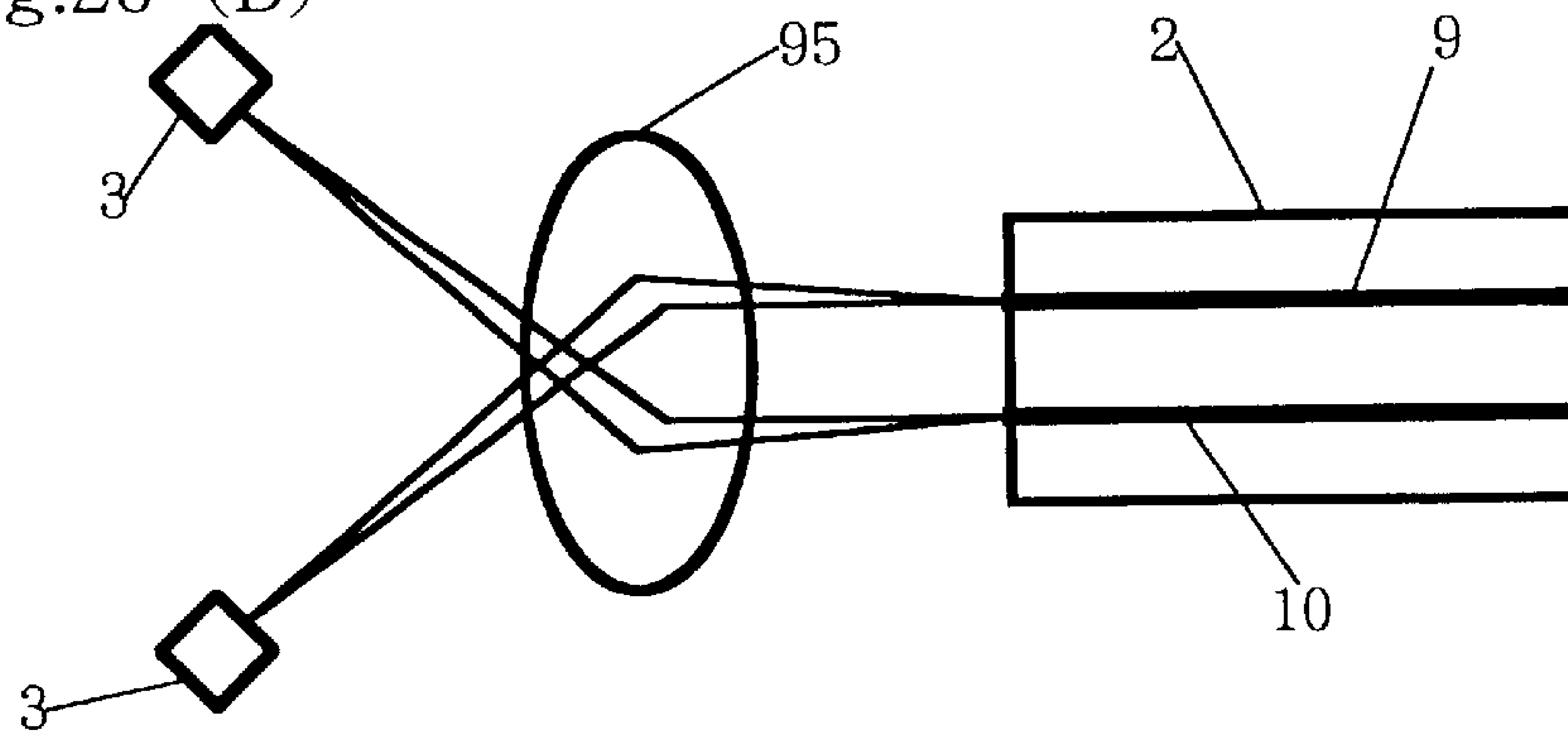

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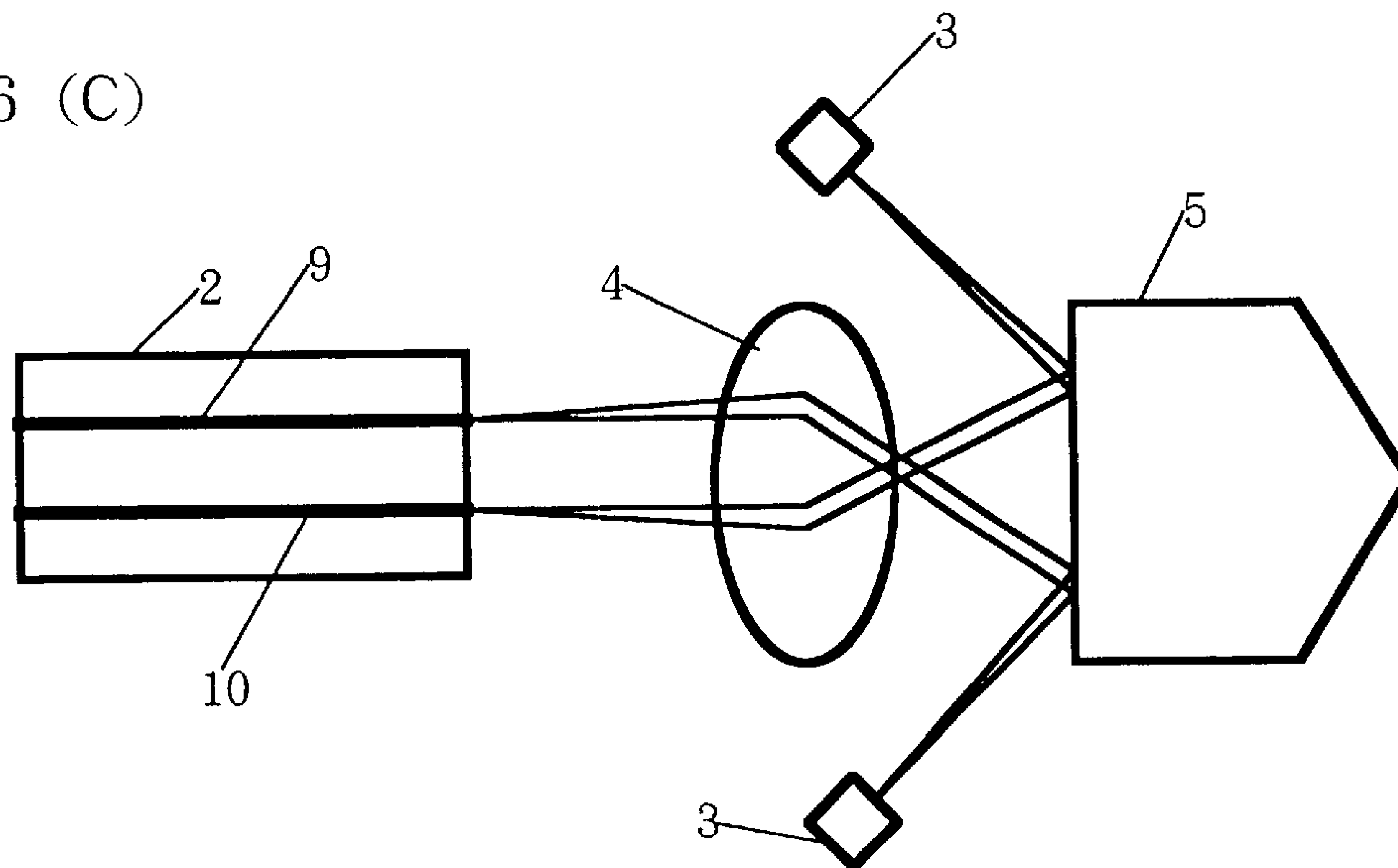

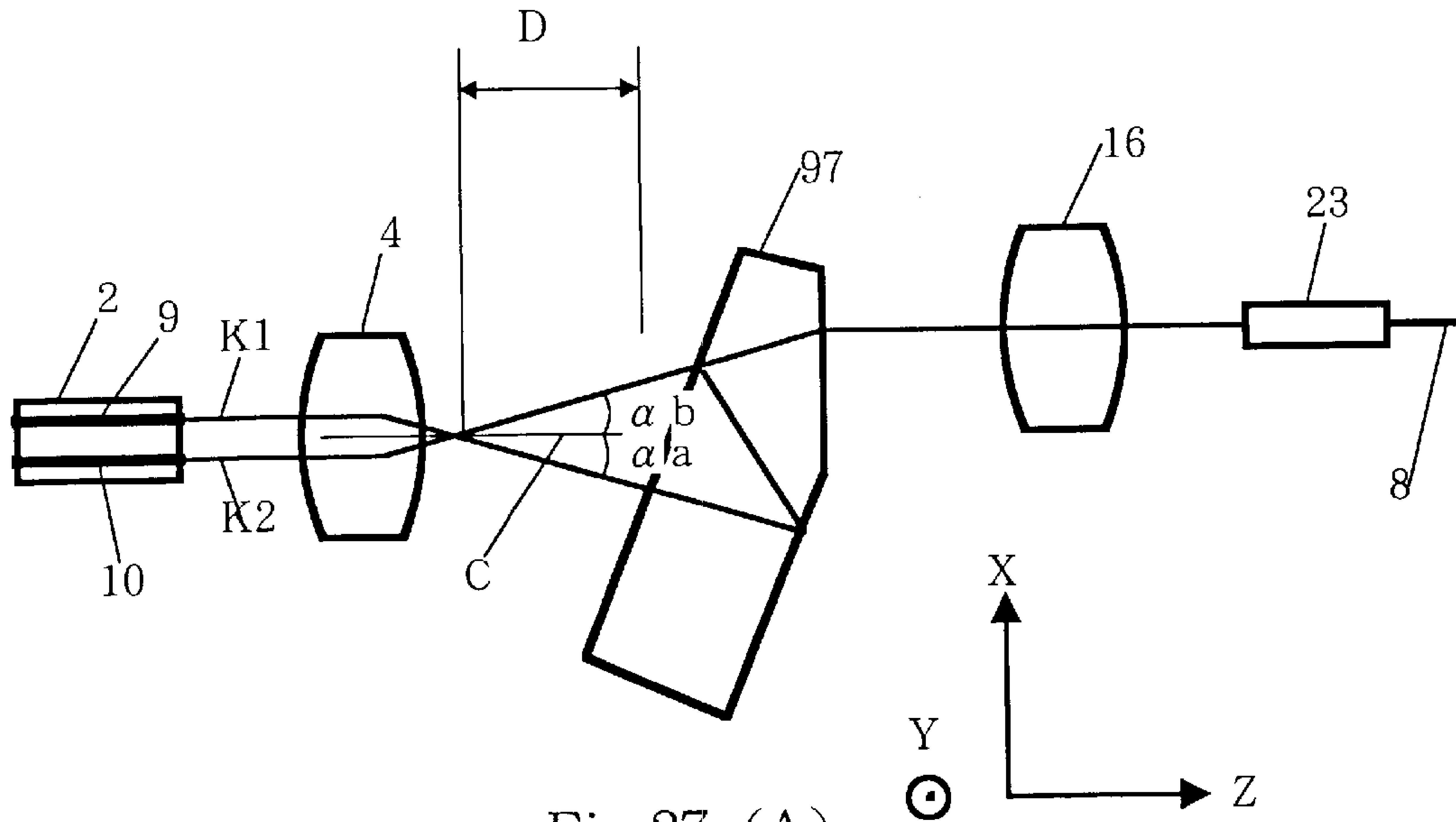

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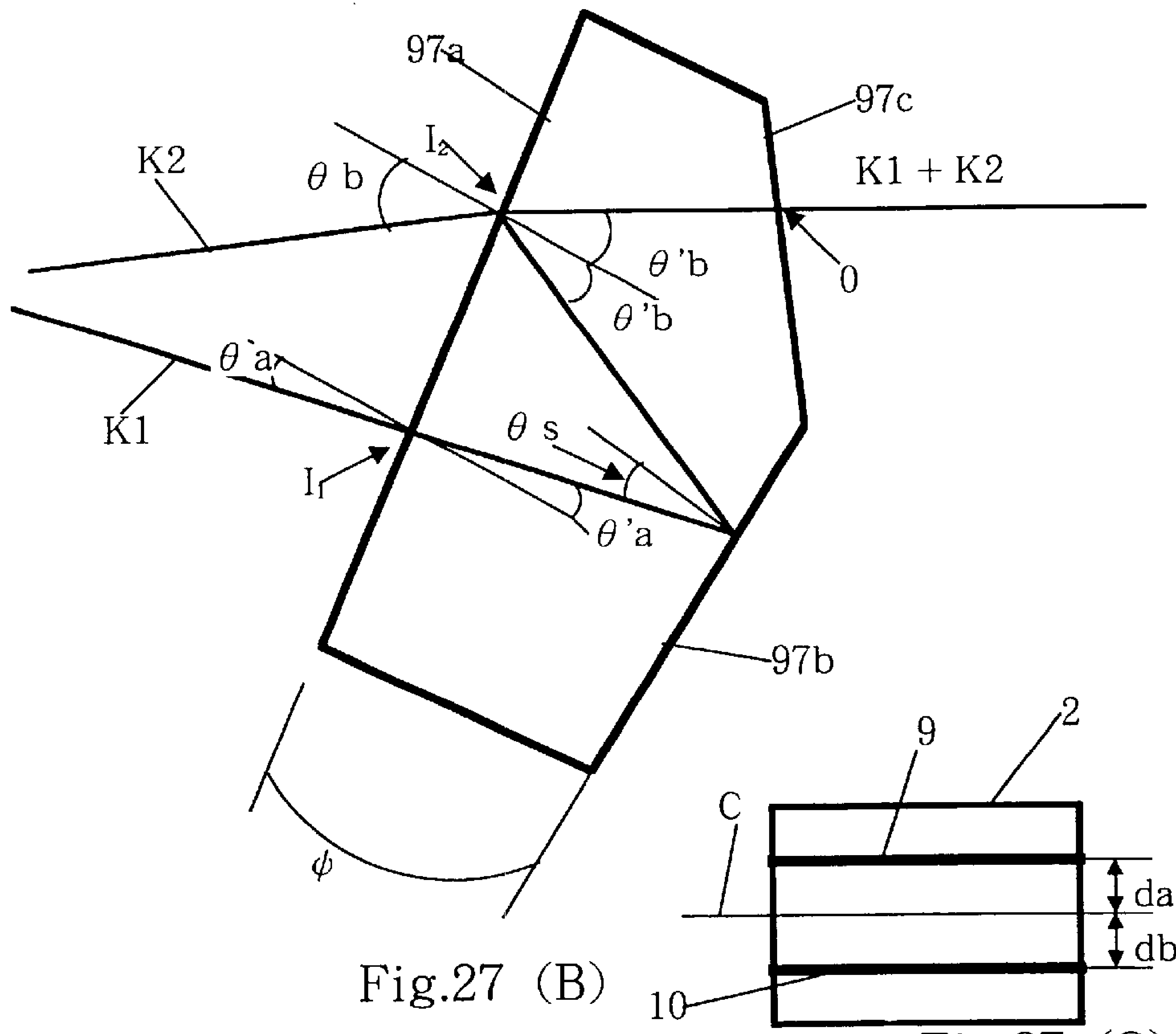

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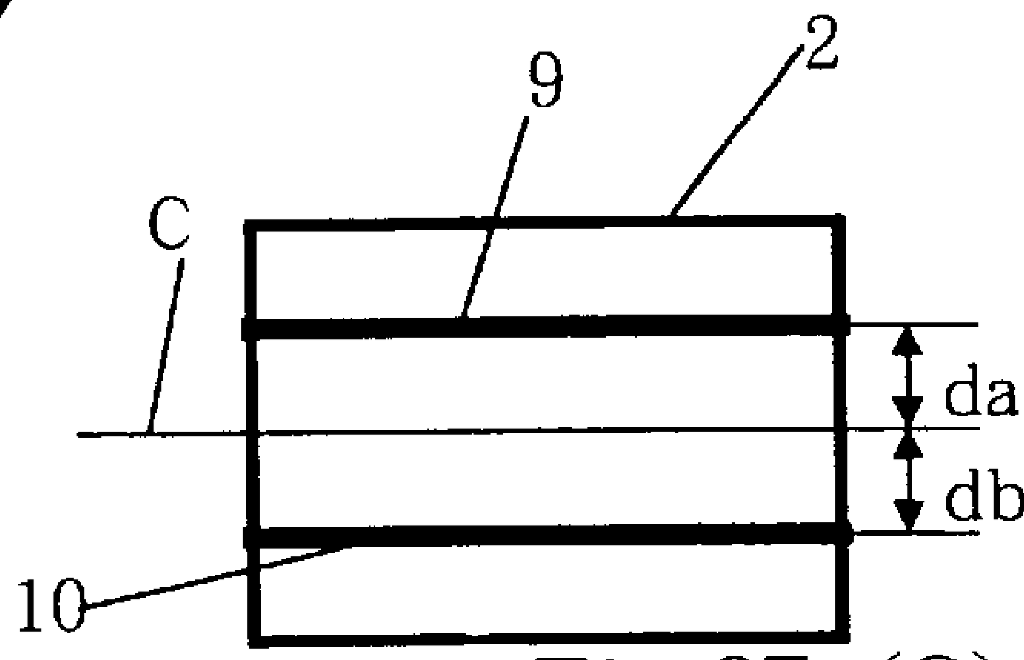

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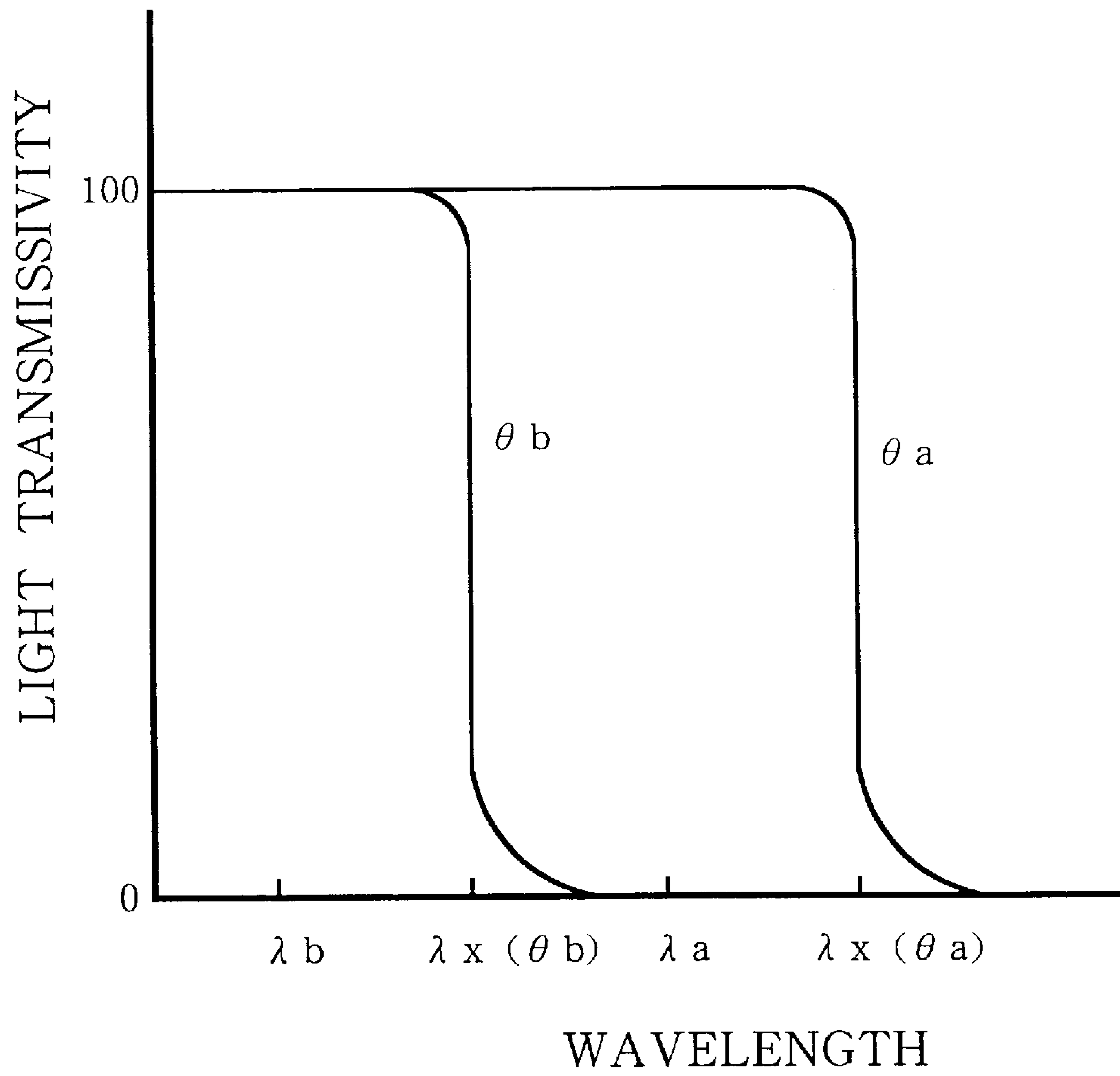

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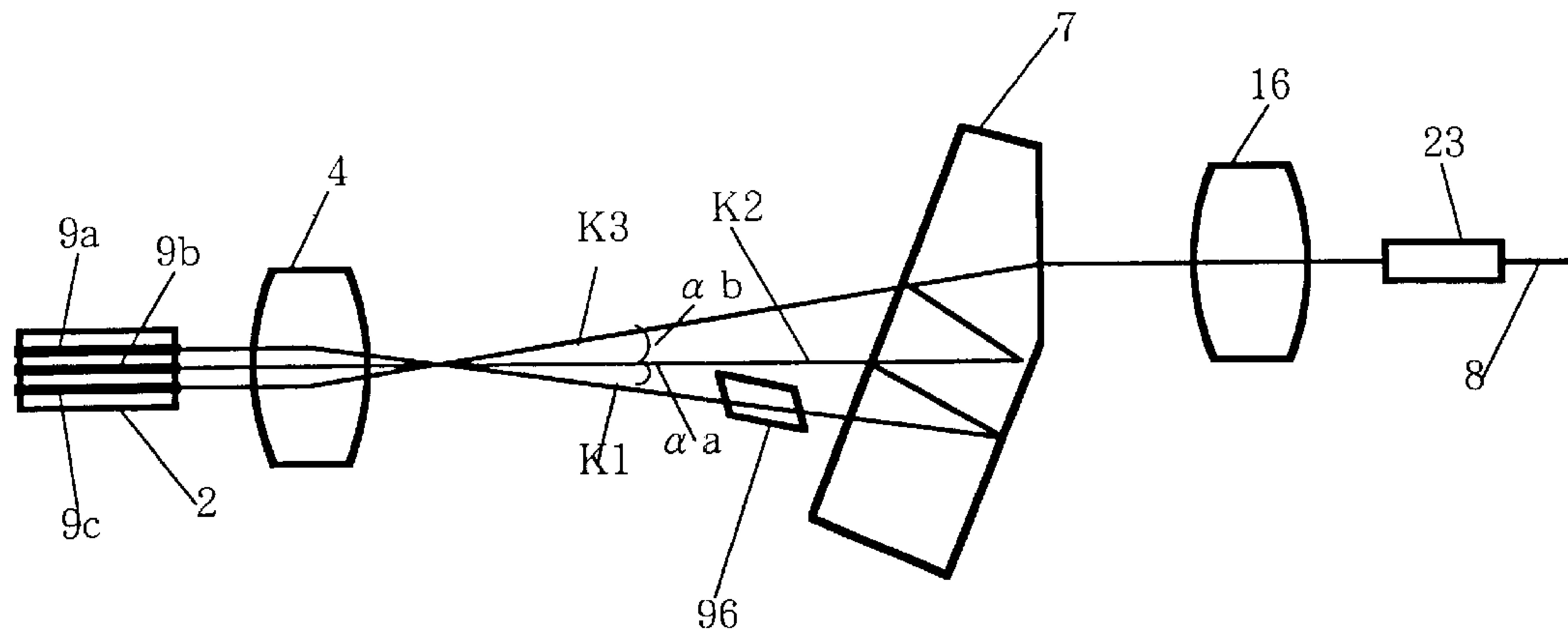

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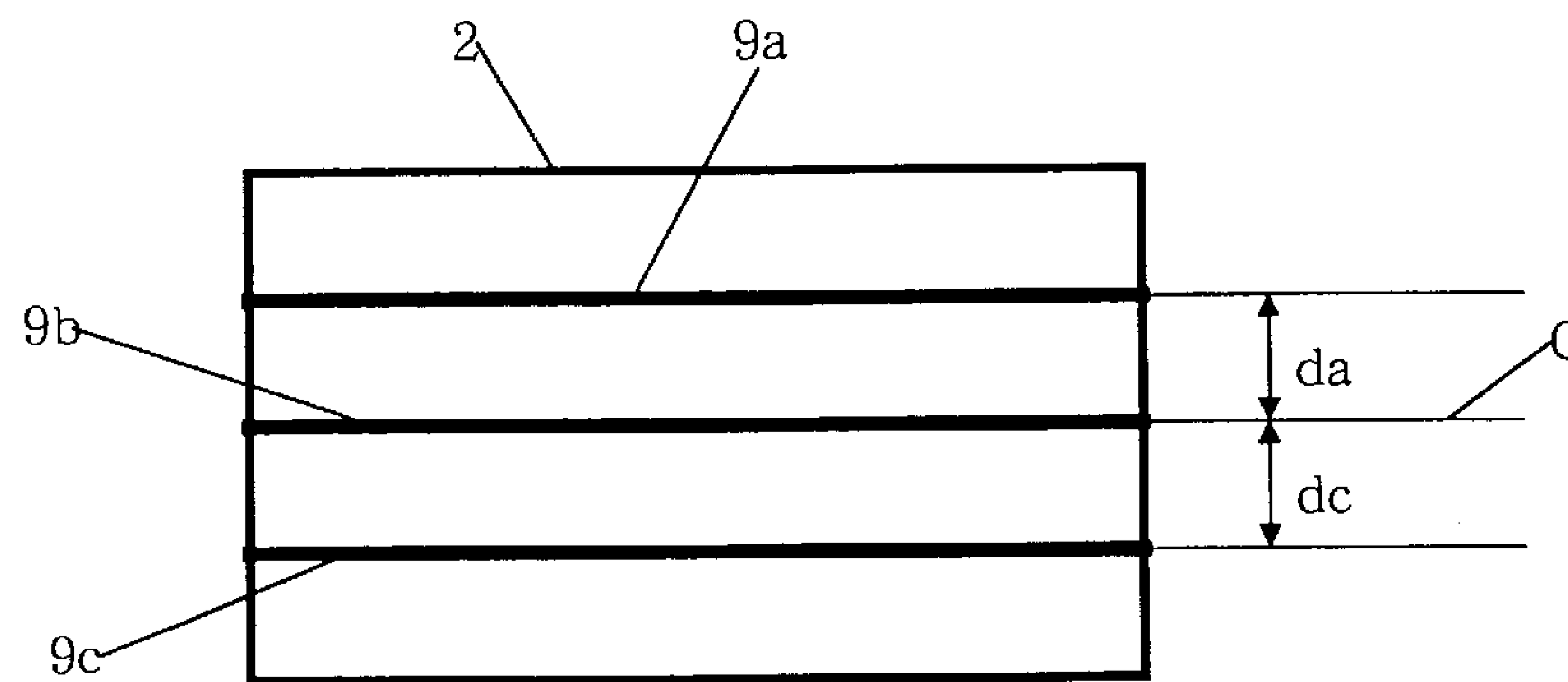

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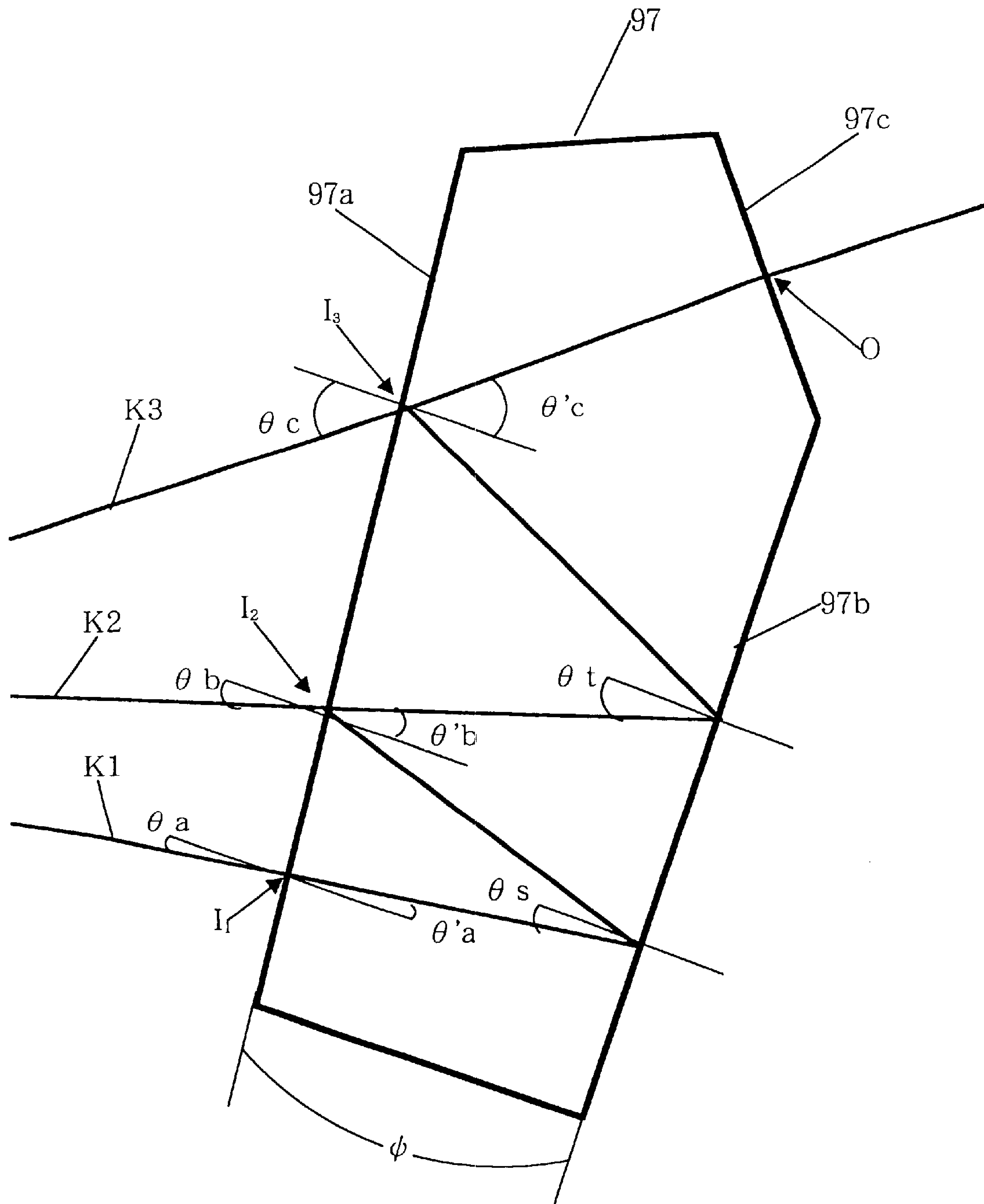


Fig.30

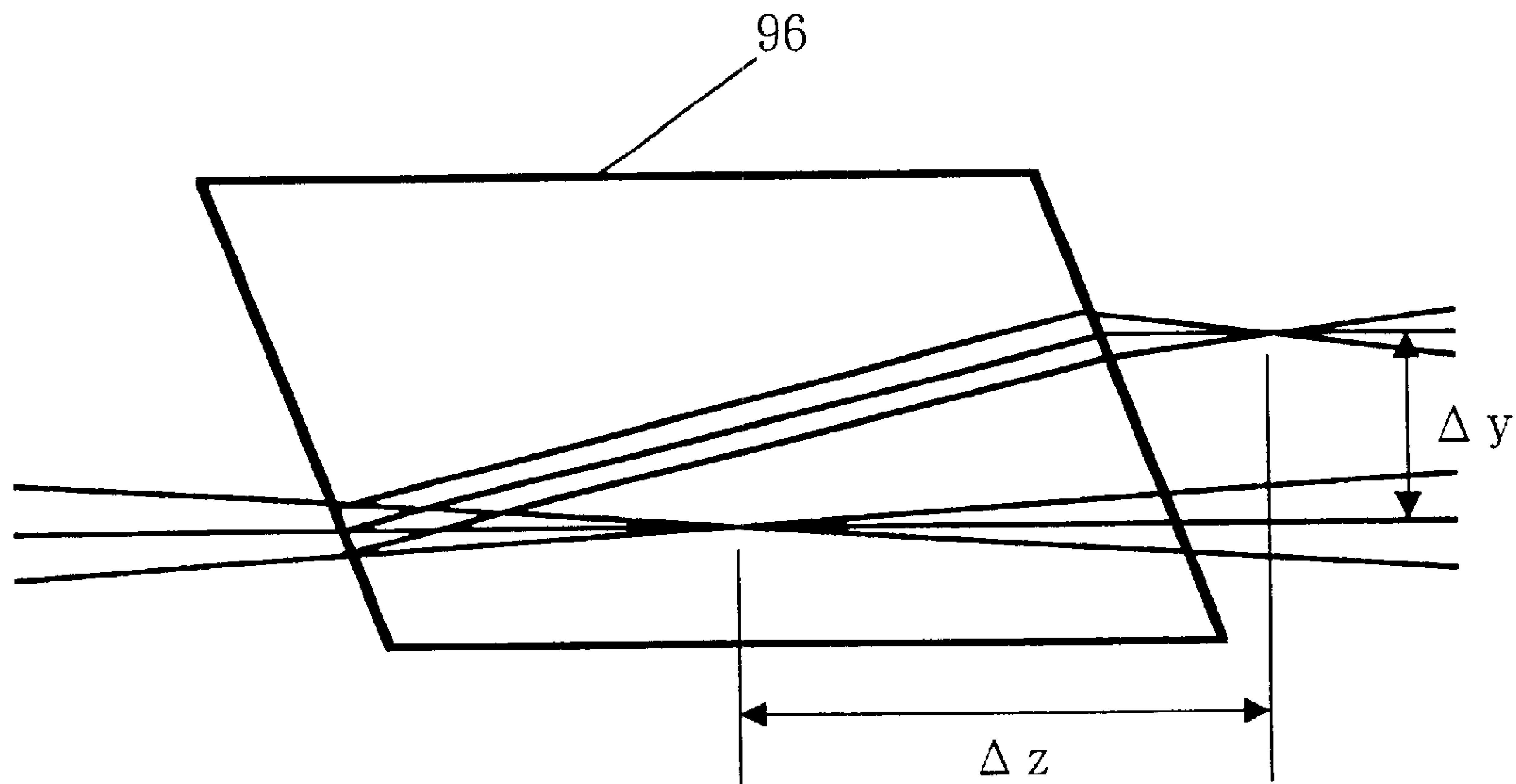


FIG.31 (A)

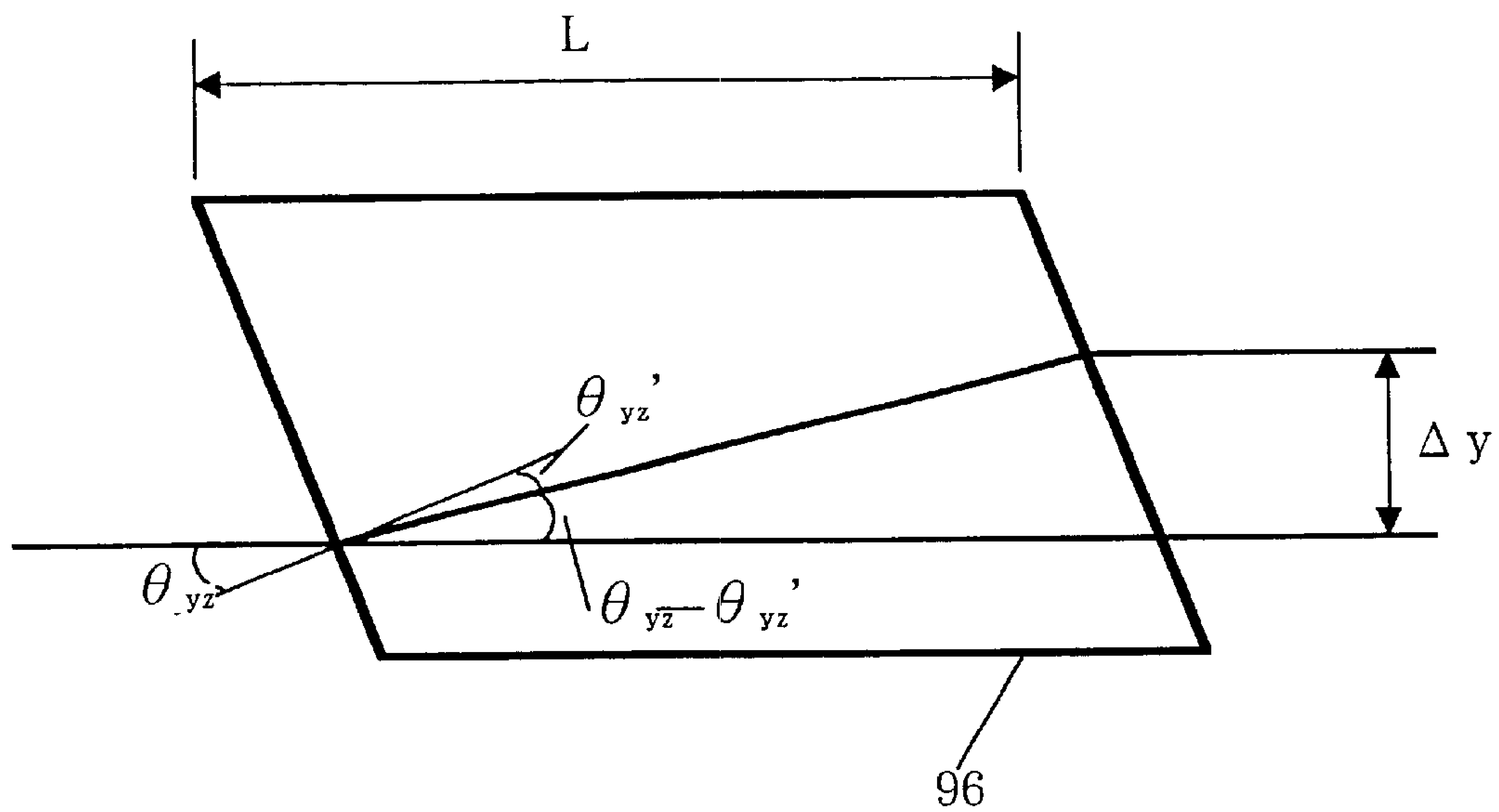
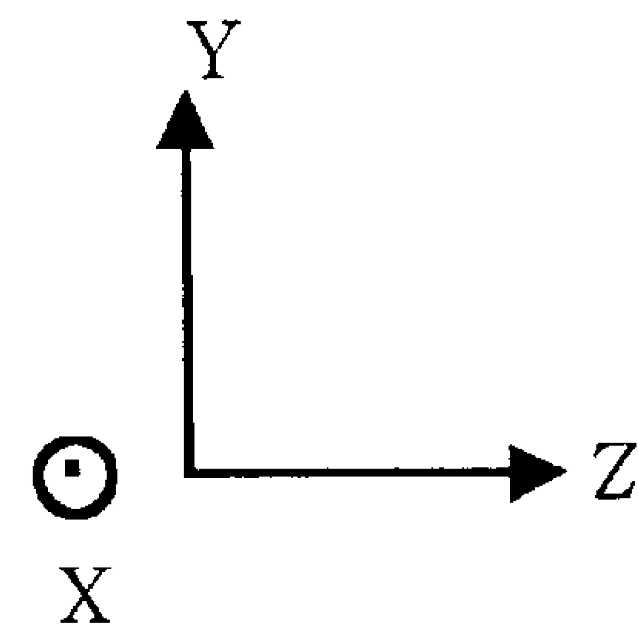


FIG.31 (B)



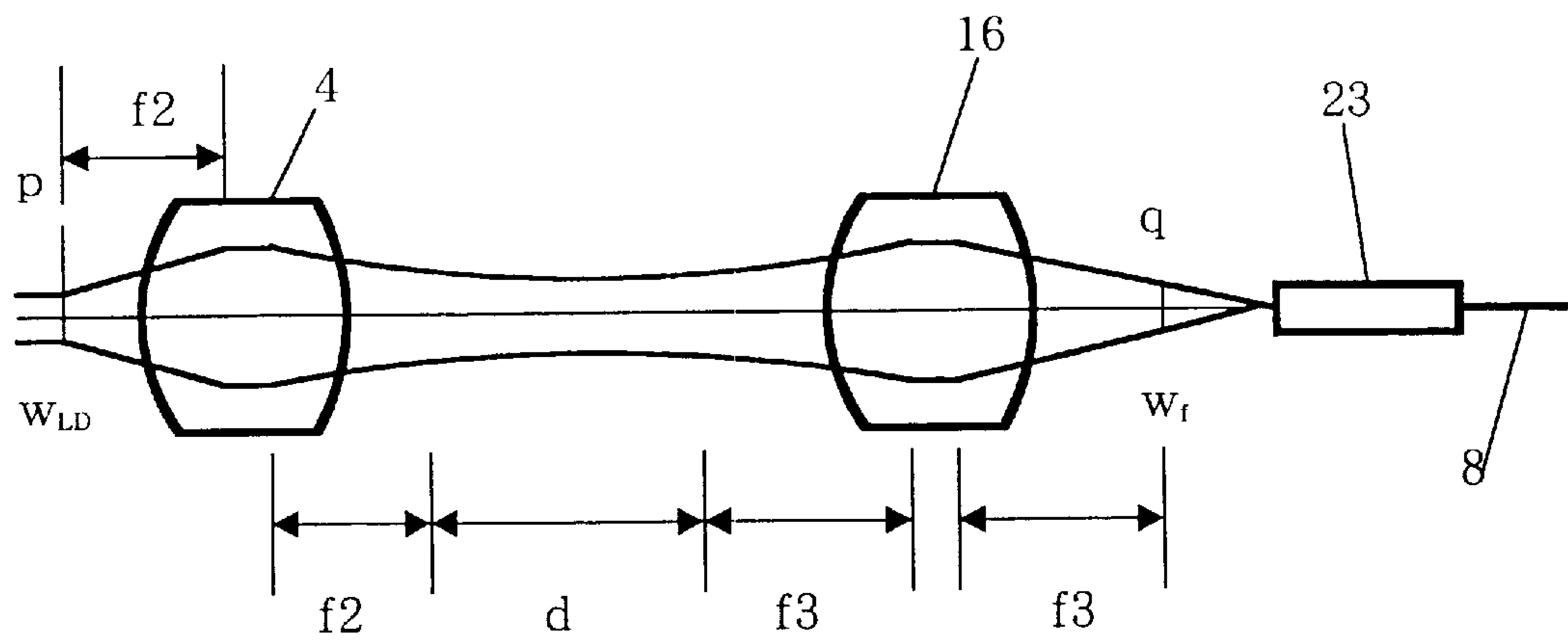


FIG.32

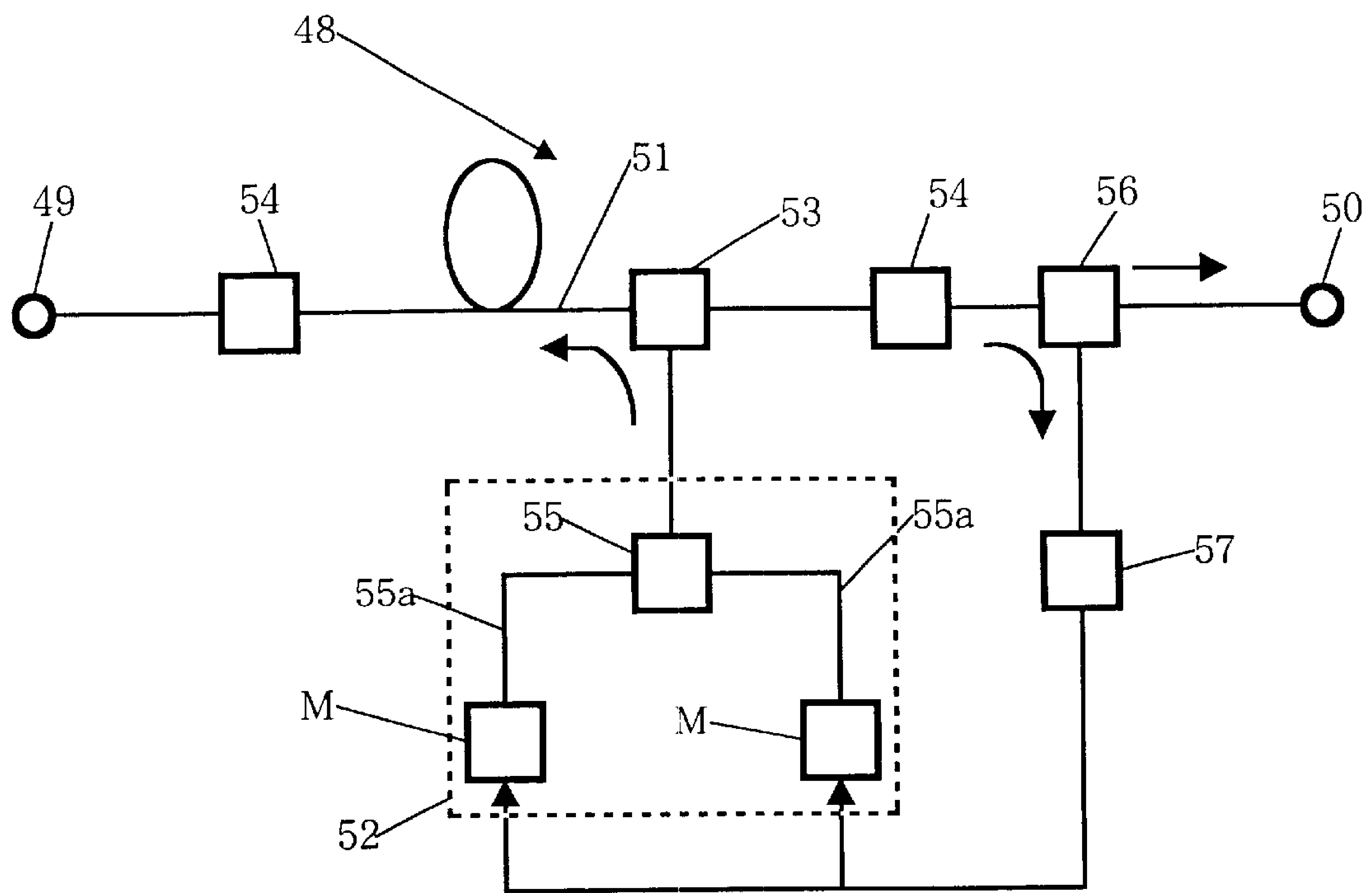


Fig.33

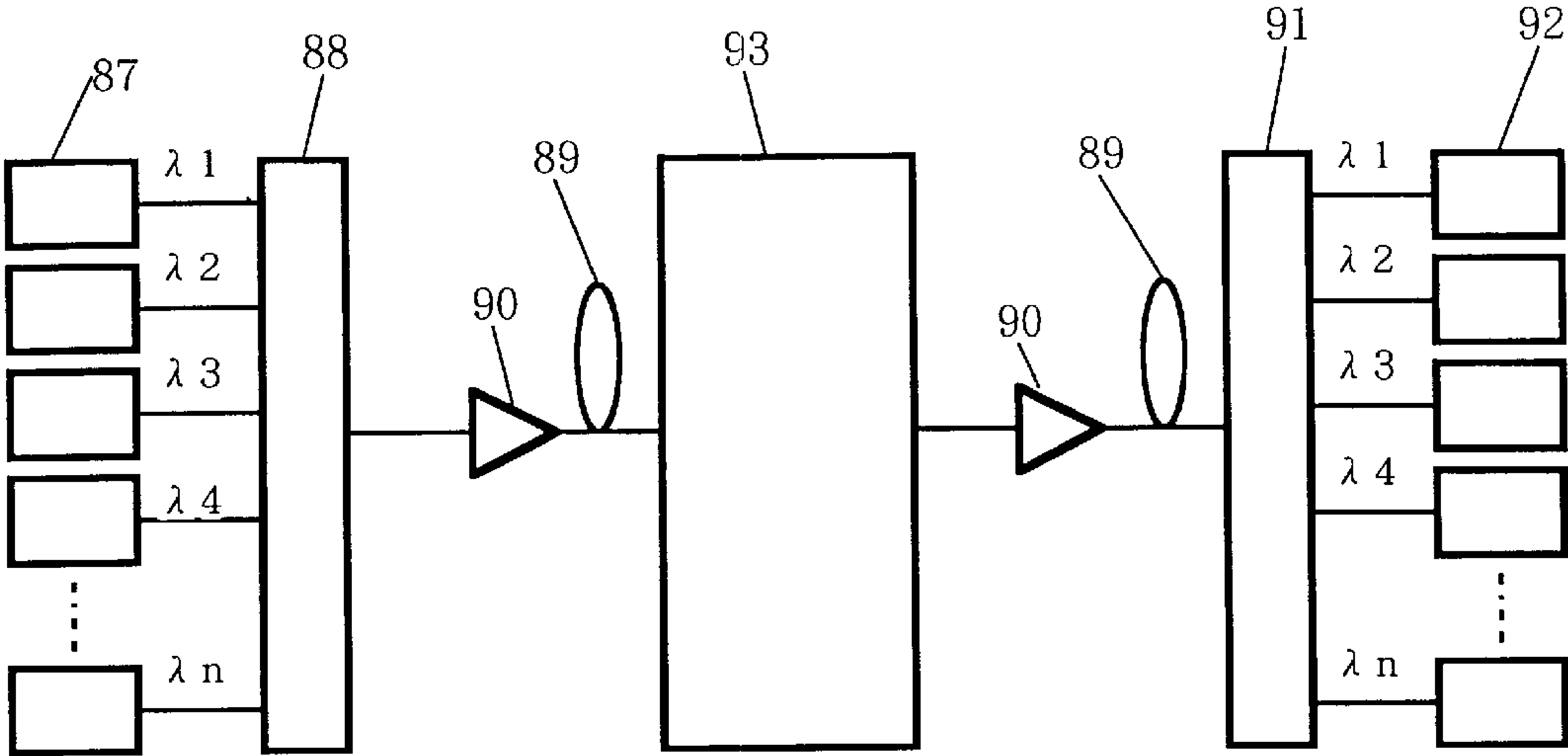


Fig.34

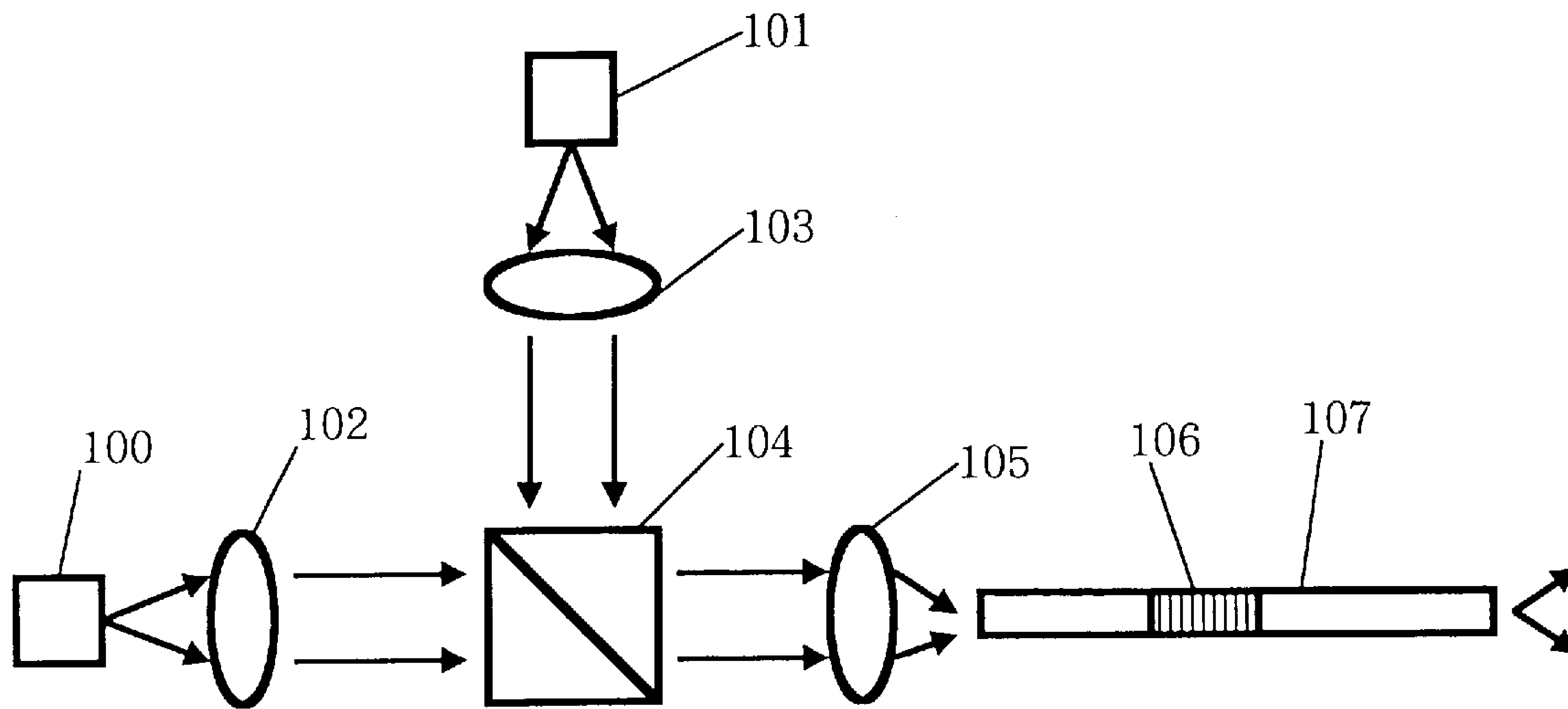
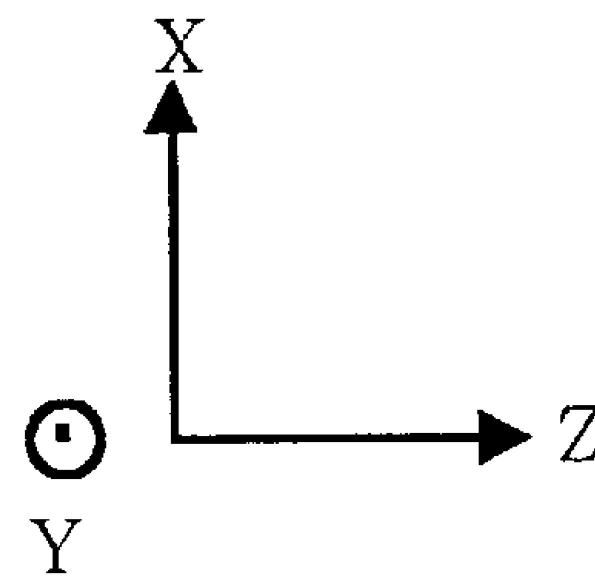


Fig.35



SEMICONDUCTOR LASER MODULE, MANUFACTURING METHOD THEREOF AND OPTICAL AMPLIFIER

BACKGROUND OF THE INVENTION

The present invention relates generally to a semiconductor laser module, a manufacturing method thereof and an optical amplifier using the semiconductor laser module, and more particularly to a semiconductor laser module employing a semiconductor laser device provided with two stripes from which two laser beams are emitted, a manufacturing method thereof and an optical amplifier.

DISCUSSION OF THE BACKGROUND

With progresses in the optical communications based on a dense wavelength division multiplexing transmission system over the recent years, a higher output is increasingly demanded to a pumping light source used for the optical amplifier.

Further, a greater expectation is recently given to a Raman amplifier as an amplifier for amplifying the beams having a much broader band than by an erbium-doped optical amplifier that has hitherto been used as the optical amplifier. The Raman amplification may be defined as a method of amplifying the optical signals, which utilizes such a phenomenon that a gain occurs on the side of frequencies as low as 13 THz on the basis of a pumping beam wavelength due to the stimulated Raman scattering occurred when the pumping beams enter an optical fiber, and, when the signal beams having the wavelength range containing the gain described above are inputted to the optical fiber in the thus pumped (excited) state, these signal beams are amplified.

According to the Raman amplification, the signal beams are amplified in a state where a polarizing direction of the signal beams is coincident with a polarizing direction of the pumping beams, and it is therefore required that an influence by a deviation between polarizing planes of the signal beam and of the pumping beam be minimized. For attaining this, a degree of polarization (DOP) has hitherto been reduced by obviating the polarization of the pumping beam (which may be called depolarization).

What is known as a conventional semiconductor laser module used as a pumping light source or the like of an optical amplifier, is a semiconductor laser module in which two fluxes of laser beams are polarization-synthesized and thus outputted from an optical fiber.

For example, Japanese Patent Application Laid-open No. Sho 60-76707 discloses a semiconductor laser module including first and second semiconductor laser devices, a polarization rotating element, a polarizing element, and optical fiber and a lens. The first and second semiconductor laser devices having their optical axes and polarizing planes that are parallel to each other and also their exit edge surfaces substantially coincident with each other, are disposed on a heat sink and emit first and second laser beams, respectively. The polarization rotating element is disposed on a light path for the first laser beam emitted from the first semiconductor laser device, and sets the polarizing plane of the first laser beam at a right angle to the polarizing plane of the second laser beam by rotating the former polarizing plane by 90°. The polarizing element serves to converge the light paths for the first and second laser beams with the polarizing planes orthogonal to each other by a birefringence effect. The optical fiber serves to receive the laser beams emerging from the polarizing element and let the laser beams travel outside. The lens serves to lead the laser beams converged by the polarizing element to the optical fiber. According to this semiconductor laser module, the first and second semiconductor laser devices are packaged as a unit (this technology will hereinafter be called a prior art 1).

Further, Japanese Patent Application Laid-open No. 2000-31575 discloses a semiconductor laser module including a thermoelectric cooler, first and second semiconductor laser devices mounted on the electron cooling device, first and second condenser lenses each for converging first and second laser beams emitted from the first and second semiconductor laser devices, a polarization-synthesizing element for polarization-synthesizing the first and second laser beams, and an optical fiber for receiving the laser beams emerging from the polarization-synthesizing element and letting the laser beams travel outside. Moreover, each of the first and second semiconductor laser devices is constructed as an LD (laser diode) array in which the laser diodes are arrayed at a pitch between center portions of emission parts on the order of 500 μm. Further, each of the first and second condenser lenses is configured as a lens array for converging the laser beams such as a spherical lens array, a Fresnel lens array and so on (this technology will hereinafter be called a prior art 2).

The prior art 1 has the configuration in which the laser beams from the semiconductor laser device are received directly by the polarization rotating element or the polarizing element. As recognized by the prior inventors, obtainment of a high optical coupling efficiency with the configuration of the prior art 1 therefore involves a geometrical design in which a space between the semiconductor laser device and the lens is set on the order of 300 to 500 μm. In fact, however, it is highly difficult to dispose the polarization rotating element and the polarizing element between the semiconductor laser device and the lens. A wider space can be formed by increasing a size of the lens, however, there remains a problem in that a size of the package becomes several times as large as package used at the present, which leads to a scale-up of the semiconductor laser module.

On the other hand, the prior art 2 has the configuration that the condenser lenses are disposed corresponding to the two semiconductor laser devices and thereafter the laser beams are polarization-synthesized, and therefore obviates the problem of the space in the prior art 1.

In the configuration, and as recognized by the prior inventors however, each lens receives one beam emitted at a comparatively wide interval (the inter-emission-center pitch; 500 μm) respectively, thereby obtaining the two laser beams parallel to each other. This configuration consequently brings about the scale-up of the semiconductor laser device with the result that a quantity of the semiconductor chips acquired from one sheet of wafer decreases, and is therefore unsuited to mass-production. If a space between the stripes of the semiconductor laser device is set to be narrow in order to obviate this problem, the lens needs downsizing, and the beams emerging from the respective stripes are hard to split from each other. It is therefore difficult to perform the succeeding polarizing synthesization and the light synthesization as well.

Further, it is required that the lens be positioned with respect to the laser beam emitted from the semiconductor laser device, and hence the problem arises herein that a manufacturing process becomes complicated, and the manufacturing is time-consuming. According to the prior art 2, the lens includes the use of a lens array (such as a spherical lens array or, a Fresnel lens array) that is normally unused in

order to obviate the positioning difficulty. The prior art 2 therefore has such a problem that the manufacturing cost is high, and it takes much time to manufacture the lens array described above.

SUMMARY OF THE INVENTION

In contrast to the prior art, the embodiments of the present invention are for a semiconductor laser module, a manufacturing method thereof and an optical amplifier that are capable of obtaining a high optical coupling efficiency, attaining a down-size and a mass-production, and reducing both of a manufacturing time and a manufacturing cost.

The present invention provides a semiconductor laser module comprising:

- a single semiconductor laser device having a first light emitting stripe and at least one other light emitting stripe which are aligned to respectively emit a first laser beam and at least one other laser beam through a one edge surface;
- a first lens positioned so that the first laser beam and the at least one other laser beam emitted from the semiconductor laser device are incident therealong, the first lens configured to separate the first laser beam and the at least one other laser beam;
- a beam synthesizing member including
  - a first input part on which the first laser beam is incident,
  - at least one other input part on which the at least one other laser beam is incident, and
  - an output part from which the first laser beam emerging from the first input part and the at least one other laser beam emerging from the at least one other input part are multiplexed and emitted as a multiplexed laser beam; and
  - an optical fiber positioned to receive the multiplexed laser beam therein.

The present invention also provides an optical amplifier using comprising:

- a pump beam generator having a plurality of semiconductor laser modules emitting multiplexed laser beams, with each semiconductor laser module including
  - a single semiconductor laser device having a first light emitting stripe and at least one other light emitting stripe which are aligned to respectively emit a first laser beam and at least one other laser beam through a one edge surface;
  - a first lens positioned so that the first laser beam and the at least one other laser beam emitted from the semiconductor laser device are incident therealong, the first lens configured to separate the first laser beam and the at least one other laser beam;
  - a beam synthesizing member including
    - a first input part on which the first laser beam is incident,
    - at least one other input part on which the at least one other laser beam is incident, and
    - an output part from which the first laser beam emerging from the first input part and the at least one other laser beam emerging from the at least one other input part are multiplexed and emitted as a multiplexed laser beam;
    - an optical fiber positioned to receive the multiplexed laser beam therein; and
    - a wave division multiplexer coupler configured to synthesize the multiplexed laser beams emitted by the plurality of semiconductor laser modules.

The present invention also provides a semiconducting laser module, comprising:

- means for producing a first laser beam and a second laser beam from a single semiconductor laser device;
- means for separating the first laser beam and a second laser beam; and
- means for multiplexing the first laser beam and the second laser beam into a multiplexed laser beam.

The present invention also provides a method for generating a multiplexed laser beam, comprising steps of

- producing a first laser beam and a second laser beam from a single semiconductor laser device;
- separating the first laser beam and a second laser beam; and
- multiplexing the first laser beam and the second laser beam into a multiplexed laser beam.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. **1**(A) is a side sectional view showing a configuration of a semiconductor laser module in accordance with a first embodiment of the present invention; FIG. **1**(B) is a side view showing a state where a semiconductor laser device is fixed onto a heat sink;

FIG. **2** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with the first embodiment of the present invention;

FIG. **3**(A) is a side view showing a configuration of a prism; FIG. **3**(B) is a plan view thereof;

FIG. **4**(A) is a plan view showing a polarization synthesizing module; FIG. **4**(B) is a side sectional view thereof; FIG. **4**(C) is a front view thereof;

FIG. **5** is a graph showing a spectrum when a drive current **2**A (**1**A applied per stripe) is applied in a double-stripe type semiconductor laser module;

FIG. **6** is a graph showing a fiber output versus an LD drive current in the double-stripe type semiconductor laser module;

FIGS. **7**(A) and **7**(B) are explanatory diagrams showing a step of aligning a first lens;

FIGS. **8**(A) to **8**(C) are explanatory views showing a configuration of the semiconductor laser device; FIGS. **8**(B) and **8**(C) are sectional views each taken along the line a—a in FIG. **8**(A);

FIG. **9** is an explanatory view showing another example of the semiconductor laser device;

FIG. **10** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a second embodiment of the present invention;

FIG. **11** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a third embodiment of the present invention;

FIG. **12** is a fragmentary perspective view showing a polarization synthesizing module in accordance with a fourth embodiment of the present invention;

FIG. **13** is a side sectional view showing the polarization synthesizing module shown in FIG. **12**;

FIG. **14** is an explanatory diagram schematically showing a semiconductor laser device in accordance with the fifth embodiment of the present invention;

FIGS. **15**(A) to **15**(C) are explanatory views showing a configuration of the semiconductor laser device in accordance with a sixth embodiment of the present invention;

FIGS. **15**(B) and **15**(C) are a sectional view taken along the line b-b in FIG. **15**(A) and a sectional view taken along the line c-c in FIG. **15**(A), respectively;

FIG. **16** is a graph showing a relationship between an oscillation wavelength spectrum and an oscillation longitudinal mode in the semiconductor laser device in accordance with the sixth embodiment of the present invention;

FIGS. **17**(A) and (B) are graphs showing a relationship in laser optical output power between the single oscillation longitudinal mode and a plurality of oscillation longitudinal modes, and a threshold value of stimulated Brillouin scattering;

FIGS. **18**(A) to **18**(C) are vertical sectional views each showing in the longitudinal direction a configuration of the semiconductor laser device in accordance with a seventh embodiment of the present invention;

FIG. **19** is a vertical sectional view showing in the longitudinal direction a configuration of the semiconductor laser device in accordance with an eighth embodiment of the present invention;

FIG. **20** is an explanatory diagram showing a fluctuation in period of diffraction gratings provided in the semiconductor laser device shown in FIG. **19**;

FIG. **21** is an explanatory diagram showing a modified example for actualizing the fluctuation in period of the diffraction gratings provided in the semiconductor laser device shown in FIG. **19**;

FIG. **22** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with an eleventh embodiment of the present invention;

FIG. **23** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a twelfth embodiment of the present invention;

FIG. **24** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a thirteenth embodiment of the present invention;

FIG. **25** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a fourteenth embodiment of the present invention;

FIG. **26** is an explanatory diagram showing an example of a photo diode (light receiving element) in accordance with a fifteenth embodiment of the present invention;

FIG. **27** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a sixteenth embodiment of the present invention;

FIG. **28** is a graph showing a beam transmissivity when entering a wavelength selection filter **7***a;*

FIG. **29** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a seventeenth embodiment of the present invention;

FIG. **30** is an explanatory diagram showing a PBC (polarization beam combiner) of a wedge-shaped prism;

FIG. **31** is an explanatory diagram showing a light path correction prism;

FIG. **32** is an explanatory diagram showing coupling of Gaussian beams;

FIG. **33** is a block diagram showing a configuration of a Raman amplifier in accordance with a twelfth embodiment of the present invention;

FIG. **34** is a block diagram showing an architecture of a WDM communication system to which the Raman amplifier shown in FIG. **23** is applied; and

FIG. **35** is an explanatory diagram showing a conventional semiconductor laser device disclosed in U.S. Pat. No. 5,589,684.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will hereinafter be described with reference to the accompanying drawings.

First Embodiment

FIG. **1**(A) is a side sectional view showing a configuration of the semiconductor laser module in accordance with a first embodiment of the present invention. FIG. **2** is an explanatory diagram schematically showing the configuration of the semiconductor laser module in accordance with the first embodiment of the present invention.

As shown in FIG. **1**(A), a semiconductor laser module **M1** in accordance with the first embodiment of the present invention includes a package **1** of which an interior is hermetically sealed, a semiconductor laser device **2**, encased in the package **1**, for emitting laser beams, a photo diode (a light receiving element) **3**, a first lens **4**, a prism **5**, a half-wave plate (a polarization rotating element) **6**, a PBC (polarization beam combiner) **7** serving as an optical synthesizing element and an optical fiber **8**.

The semiconductor laser device **2** includes, as shown in FIG. **2**, a first stripe **9** (a stripe-shaped light emitting portion) and a second stripe **10** disposed with an interval on the same plane and extending in parallel in the longitudinal direction. The semiconductor laser device **2** emits a first laser beam **K1** and a second laser beam **K2** respectively from edge surfaces of the first and second stripes **9**, **10**. **K1** and **K2** shown in FIG. **2** represent trajectories of the centers of the beams that exit the first and second stripes **9**, **10**, respectively. The beam travels, as indicated by a broken line in FIG. **2**, with some divergence (spread) about the center thereof. A space between the first stripe **9** and the second stripe **10** is set as 100 μm or less e.g., approximately 40–60 μm in order for the beams **K1**, **K2** exiting these stripes **9**, **10** to enter one piece of first lens **4**. Moreover, the space between the stripes is narrow, whereby a difference in optical output characteristic between the stripes decreases.

As shown in FIG. **1**(A), the semiconductor laser device **2** is fixedly fitted onto a chip carrier **11**. Note that the semiconductor laser device **2** emits the two laser beams **K1**, **K2** and is therefore easier to become exothermic than a semiconductor laser device for emitting the single laser beam. It is therefore preferable that the semiconductor laser device **2** be fixedly fitted onto a heat sink **58** composed of a material exhibiting a high thermal conductivity such as diamond and so forth, and that the heat sink **58** be fixedly fitted onto the chip carrier **11**.

The photo diode **3** receives a monitor-oriented laser beam emitted from a roar-sided (left-sided in FIG. **1**(A)) edge surface **2***b* (see FIG. **2**) of the semiconductor laser device **2**. The photo diode **3** is fixedly attached to a photo diode carrier **12**.

The first and second laser beams **K1**, **K2** exiting a front-sided (right-sided in FIG. **1**(A)) edge surface **2***a* of the semiconductor laser device **2** are incident upon the first lens **4**. The first lens **4** functions so that these laser beams **K1**, **K2** travel-therethrough and intersect each other to subsequently

split and expand in the arrayed direction of the stripes **9** and **10**, and focuses these beams at different focal position F1, F2, respectively (see FIG. **2**).

Normally, parallel beams transformed into a large spot size have an angular tolerance that is as strict as 0.1.degree or smaller, however, the angular tolerance slackens in the condensing optical system which converges the laser beams at focal positions F1, F2 as described above. Since the first lens **4** is disposed as a condensing optical system in this embodiment, a manufacturing tolerance and a positioning tolerance of the optical elements, as well as an angular adjusting tolerance of a beam, are slack. This is a preferable aspect.

As shown in FIG. **1**(A), the first lens **4** is held by a first lens holding member **13**. The first lens **4** is preferably positioned so that the optical axis of the first laser beam K1 emerging from the first stripe **9** and the optical axis of the second laser beam K2 emerging from the second stripe **10** show substantially a symmetry about the central axis of the first lens **4**. With this arrangement, both of the first and second laser beams K1, K2 travel through the vicinity of the central axis of the first lens **4** that is defined as an area with a small aberration, and hence there is a decreased scatter on the wave surfaces of the laser beams, with the result that the optical coupling efficiency to the optical fiber **8** rises. As a result, a higher optical output may be obtained from the semiconductor laser module M1. Note that the first lens **4** preferably involves, the use of an aspherical lens exhibiting a small spherical aberration and a high optical coupling efficiency to the optical fiber **8** to be obtained.

The prism **5** is disposed between the first lens **4** and the PBC **7** and adjusts the light paths, substantially collimates the optical axes, of the first and second laser beams K1, K2, thus letting the laser beams K1, K2 exit the prism **5** itself. The prism **5** is composed of an optical glass of BK7 (borosilicate crown glass) and so on. The optical axes of the first and second laser beams K1, K2 traveling in non-parallel from the first lens **4** are collimated by refraction of the prism **5**, and hence this facilitates manufacturing the PBC **7** disposed in rear of the prism **5** and makes it feasible to downsize the semiconductor laser module M1 by downsizing the PBC **7**.

FIG. **3**(A) is a side view showing a configuration of the prism **5**, and FIG. **3**(B) is a plan view thereof. As shown in FIGS. **3**(A) and **3**(B), the prism **5** is approximately 1.0 mm in its entire length L1, and includes an incident surface **5***a* formed flat and an exit surface **5***b* inclined at a predetermined angle a (a is 3.2°±0.1°).

As shown in FIG. **2**, the half-wave plate **6** admits an incidence of only the first laser beam K1 of the first and second laser beams K1, K2 passing through the prism **5**, and rotates by 90 degrees a polarizing surface of the first laser beam K1 incident thereupon. The first lens **4** makes the first and second laser beams K1, K2 split thoroughly, whereby the half-wave plate **6** becomes easy to dispose.

The PBC **7** has a first input part **7***a* on which the first laser beam K1 is incident, a second input part **7***b* on which the second laser beam K2 is incident, and an output part **7***c* where the first laser beam entering the first input part **7***a* and the second laser beam K2 entering the second input part **7***b* are multiplexed and thus exit. The PBC **7** may be, for instance, a birefringence element through which the first laser beam K1 travels as an ordinary ray to the output part **7***c* and the second laser beam K2 travels as an extraordinary ray to the output part **7***c*. The PBC **7**, if being the birefringence element, is composed of, e.g., TiO_2 (rutile) to obtain a high index of birefringence and a large split width between the laser beams.

In the first embodiment, a polarization synthesizing module **59** is adopted in which the prism **5**, the half-wave plate **6** and the PBC **7** are fixed to the same holder member **14**. FIG. **4**(A) is a plan view showing the polarization synthesizing module **59**. FIG. **4**(B) is a side sectional view thereof. FIG. **4**(C) is a front view thereof. As shown in FIGS. **4**(A) to **4**(C), the holder member **14** of the polarization synthesizing module **59** is composed of a material (for example, SUS403, SUS304 and so on) suitable for YAG laser welding. The holder member **14** is approximately 7.0 mm in its entire length L2 and is formed substantially in a cylindrical shape as a whole. The holder member **14** is formed inside with an rectangular accommodation space **14***a* in which the prism **5**, the half-wave plate **6** and the PBC **7** are fixedly provided, respectively. The holder member **14** is opened at its upper portion and is flat in its lower portion.

This configuration greatly facilitates adjusting the positions of the prism **5** and the PBC **7** about a central axis C1 so that both of the first laser beam K1 incident upon the first input part **7***a* of the PBC **7** and the second laser beam K2 incident upon the second input part **7***b* thereof, exit the output part **7***c*.

Thus, these optical elements are set integral within the holder member **14**, and it is therefore possible to adjust a degree of how much the laser beams K1, K2 overlap with each other on the X-Y plane simply by moving the holder member **14**.

As shown in FIG. **2**, the optical fiber **8** receives the laser beams exiting the output part **7***c* of the PBC **7** and lets the laser beams travel outside the package **1**. The optical fiber **8** is, as shown in FIG. **2**, provided with a beam reflection element **15** consisting of an FBG (fiber Bragg grating) that reflects the beams having a predetermined wavelength range. This beam reflection element **15** reflects the beams having the predetermined wavelength back to the semiconductor laser device **2**. With this beam reflection element **15**, an oscillation wavelength of the semiconductor laser device **2** is fixed, and an oscillation spectral width can be decreased. Accordingly, if the laser beams emitted from the semiconductor laser module M1 are multiplexed by a wavelength synthesizing coupler (WDM: wavelength division multiplexing) and thus used as a pumping light source of an erbium-doped optical amplifier or a Raman amplifier, high-output multiplexed beams can be obtained by restraining a loss of the wavelength synthesizing couple down to a low level. If used for the Raman amplifier, a fluctuation in gain of the Raman amplification can be restrained. The beam reflection element **15** is formed by irradiating a core of the optical fiber **8** with ultraviolet rays serving as interference fringes through, e.g., a phase mask, and consequently causing periodic changes in refractive index.

A second lens **16** for optical-coupling the laser beams emerging from the output part **7***c* of the PBC **7** to the optical fiber **8**, is disposed between the PBC **7** and the optical fiber **8**. The first lens **4** is positioned so that the first and second laser beams K1, K2 are focused on points (F1, F2) between the first lens **4** and the second lens **16**. With this contrivance, a length of the semiconductor laser module M1 in the optical-axis direction can be reduced. As a result, it is feasible to provide the highly reliable semiconductor laser module M1 exhibiting an excellent passage-of-time stability of the optical coupling of the semiconductor laser device **2** to the optical fiber **8** under, e.g., a high-temperature environment.

As shown in FIG. **1**, the chip carrier **11** to which the semiconductor laser device **2** is fixed and the photodiode carrier **12** to which the photo diode **3** is fixed, are fixed by soldering onto a first base plate **17** taking substantially an L-shape in section. It is preferable that the first base plate **17** be composed of a CuW based alloy and so on in order to enhance a capacity of transferring the heat evolved by the semiconductor laser device **2**.

The first lens holder member **13** to which the first lens **4** is fixed and the polarization synthesizing module **59** with the prism **5**, the half-wave plate **6** and the PBC **7** fixed to the holder member **14**, are fixed by the YAG laser welding onto a second base plate **18** through a first support member **19***a* and a second support member **19***b*, respectively. It is therefore preferable that the second base plate **18** be formed of a stainless steel etc showing a high welding property. Further, the second base plate **18** is fixed by brazing onto a flat part **17***a* of the first base plate **17**.

A cooling device (thermoelectric cooler) **20** constructed of a plurality of Peltier elements are provided under the first base plate **17**. A thermistor **20***a* provided on the chip carrier **11** detects a change in temperature due to the heat transferred from the semiconductor laser device **2**. The cooling device **20** is controlled to keep constant the temperature detected by the thermistor **20***a*. This contrivance makes it feasible to increase and stabilize the output of emission of the laser beams from the semiconductor laser device **2**.

A window **1***b* upon which the beams penetrating the PBC **7** are incident is provided inside the flange **1***a* formed at the side area of the package **1**, and a second lens **16** for converging the laser beams is fixed at the end of the flange **1***a*. The second lens **16** is held by a second lens holding member **21** fixed by the YAG laser welding to a side edge of the flange **1***a*. A metallic slide ring **22** is fixed by the YAG laser welding to a side edge of the second lens holding member **21**.

The optical fiber **8** is held by a ferrule **23** fixed by the YAG laser welding to an interior of the slide ring **22**.

Next, operations of the semiconductor laser module M1 in accordance with the first embodiment of the present invention will be explained.

As shown in FIG. **2**, the first and second laser beams K1, K2 emitted from the front-sided edge surfaces **2***a* of the first and second stripes **9**, **10** of the semiconductor laser device **2**, penetrate the first lens **4** and intersect each other. Thereafter, the laser beams K1, K2 having a sufficient divergence split thoroughly and then enter the prism **5**. A width of divergence (D) between the first and second laser beams K1, K2 when entering the prism **5** is approximately 460 μm. The first and second laser beams K1, K2 are collimated by the prism **5** and thus exit (the width of divergence between the laser beams K1 and K2 comes to approximately 500 μm). Then, the first laser beam K1 impinges on the half-wave plate **6** and, after its polarization plane has been rotated by 90 degrees, enters the first input part **7***a* of the PBC **7**, while the second laser beam K2 enters the second input part **7***b* of the PBC **7**.

In the PBC **7**, the first laser beam K1 emerging from the first input part **7***a* and the second laser beam K2 emerging from the second input part **7***b*, are multiplexed and exit the output part **7***c*.

The laser beams emitted from the PBC **7** are converged by the second lens **16**, then incident upon the edge surface of the optical fiber **8** held by the ferrule **23**, and sent outside. Further, some proportion of the laser beams are reflected by the beam reflection element **15** of the optical fiber **8** back to the semiconductor laser device **2**, thereby forming an external resonator between the semiconductor laser device **2** and the beam reflection element **15**. Hence, the laser oscillations with a wavelength determined by the beam reflection element **15** can be done.

The monitor-oriented laser beams emerging from the rear-sided edge surface **2***b* of the semiconductor laser device **2**, are received by the photo diode **3**. An optical output or the like of the semiconductor laser device **2** is adjusted by changing the driving current for the semiconductor laser device **2** due to a light receiving quantity etc. of the photo diode **3**.

According to the semiconductor laser module M1 in accordance with the first embodiment of the present invention, the first and second laser beams K1, K2 with their polarization planes coincident with each other are emitted from the first and second stripes **9**, **10** formed at the space as narrow as 100 μm or less in the single semiconductor laser device **2**. The first and second laser beams K1, K2 are thoroughly split from each other by the first lens **4**, and thereafter the polarization planes thereof are rotated exactly by 90 degrees with the half-wave plate **6**. Namely, the polarization planes of the laser beams K1, K2 make substantially completely 90° at this time. The first and second laser beams K1, K2 are polarization-synthesized by the PBC **7** in this state, and hence the laser beams having the high output and a small degree of polarization can be emitted out of the optical fiber **8**. Further, the optical fiber **8** is formed with the FBG-based beam reflection element **15**, and therefore the laser beams with the wavelength fixed can be emitted out of the optical fiber **8**. Accordingly, the semiconductor laser module M1 can be applied as the pumping light source for an erbium-doped optical amplifier of which a high output is demanded or for a Raman amplifier required to have a low polarization dependency and a high wavelength stability.

Further, the semiconductor laser module M1 involves the use of the single semiconductor laser device **2** formed with the two stripes for emitting the two fluxes of laser beams and one piece of first lens **4** for splitting both of the laser beams K1 and K2, and therefore the time for positioning the semiconductor laser device **2** and the first lens **4** decreases. As a result, it is possible to reduce the time for manufacturing the semiconductor laser module M1.

Moreover, there has hitherto been the semiconductor laser module in which two pieces of semiconductor lasers emit the laser beams in the axial directions completely differently from each other (refer to, e.g., U.S. Pat. No. 5,589,684). This type of semiconductor laser module is, however, if designed without taking a warp or the like of the package in the axial direction into account, incapable of restraining fluctuations in the optical output due to the warp of the package that is caused by a change in the ambient temperature etc. By contrast, according to the configuration in the first embodiment, the two laser beams emitted from the single semiconductor laser device **2** travel substantially in the same direction, and hence the optical output of the laser beams emerging from the optical fiber **8** can be stabilized by restraining an influence of the warp of the package in only one direction (a Z-direction in FIG. **2**).

Further, the single semiconductor laser device **2** emits the two laser beams, and the coupling efficiencies of these two laser beams have the same tendency of fluctuations with respect to the package warp and so on. Accordingly, even when the temperature fluctuates, the degree of polarization of the laser beams emitted from the optical fiber **8** is stabilized.

Further, the use of the single semiconductor laser device **2** helps downsizing the cooling device **20** (e.g. a Peltier module) and decreasing the consumption of electric power.

Note that the consumption power, required when the cooling device radiates a tremendous quantity of heat evolved from the two stripes **9**, **10** preferably can be restrained to a large extent by creating a vacuum in the interior of the package **1** or using Xe as a filler gas.

Moreover, when attaching a polarization maintaining fiber formed with the fiber Bragg grating (FBG) to the double-stripe type semiconductor laser module for emitting the two fluxes of laser beams as in the first embodiment, more longitudinal modes can be contained within the spectral Width than in the case of the single-stripe type semiconductor laser module that has the same FBG reflection band and emits one flux of laser beams.

FIG. **5** is a graph showing a oscillation spectrum when applying a drive current **2**A (which means that a drive current **1**A is given per stripe) in the double-stripe type semiconductor laser module **M1**. As can be understood from FIG. **5**, five longitudinal modes are contained within the full width at half maximum (FWHM) of the spectrum for the double-stripe type semiconductor laser module **M1**. On the other hand, in the case of a well known single-stripe type semiconductor laser module, three or four longitudinal modes are contained within the spectral FWHM of the spectrum for at the drive current **1**A.

The polarization maintaining fiber has a refractive index that differs depending on a slow-axis and a fast-axis, and therefore reflection wavelengths selected in the two axes at the FBG differ from each other on the order of 0.4 nm. Hence, even if the spectrum corresponding to each stripe is the same as in the prior art, it can be considered that there increases the number of modes of the spectrums acquired as overlaps thereof.

In this case, when the optical output from the double-stripe type semiconductor laser module M1 in the first embodiment travels in the depolarizer, the DOP (degree of polarization) is reduced effectively. Therefore the semiconductor laser module **M1** is suitable as the pumping light source of a Raman amplifier required to have the low polarization dependency.

Further, the double-stripe type semiconductor laser module is capable of obtaining high optical output. FIG. **6** is a graph showing a fiber output versus an LD drive current in the double-stripe type semiconductor laser module. As can be understood from FIG. **6**, an optical output on the order of 600 mW can be obtained when the drive current is 2500 mA. Hence, the double-stripe type semiconductor laser module in the first embodiment is suitable for use as a pumping light source in a band of 14XX (1300 to 1550) nm for the Raman amplifier, and also as the pumping light source in bands of 980 nm and 1480 nm for erbium doped fiber amplifiers (EDFA).

Next, a method of manufacturing the semiconductor laser module M1 in accordance with the first embodiment of the present invention will hereinafter be described.

To start with, the second base plate **18** is fixed by brazing onto the flat part **17***a* of the first base plate **17**.

Subsequently, the chip carrier **11** to which the semiconductor laser device **2** is fixed and the photodiode carrier **12** to which the photo diode **3** is fixed, are fixed by soldering onto the first base plate **17**.

Next, the first lens **4** is fixed onto the second base plate **18** in a way that aligns the lens **4**. In this aligning step of the first lens **4**, the semiconductor laser device **2** is supplied with the electric current and emits the first and second laser beams K1, K2 from both of the first and second stripes **9**, **10** of the semiconductor laser device **2**. Then, after setting this beam emitting direction as a fiducial direction, the first lens **4** is inserted and positioned in the X-, Y- and Z-axis directions.

FIGS. **7**(A) and **7**(B) are explanatory diagrams showing the aligning step of the first lens **4**. The first lens **4** is, as shown in FIG. **7**(A), positioned in the X-axis direction so that an angle θ**1** made between the fiducial direction (a central axis C**2**) set in the way described above and the first laser beam **K1** is equal to an angle θ**2** made between the central axis C**2** and the second laser beam K**2**. The first lens **4** is, as shown in FIG. **7**(B), positioned in the Y-axis direction so that the first and second laser beams **K1**, **K2** travel through the center of the first lens **4**. Further, the first lens **4** is positioned in the Z-axis direction so that a spot size of the laser beam is minimized at a predetermined distance from the semiconductor laser device **2**. The first lens holding member **13**, which holds the first lens positioned in the aligning step described above, is fixed by the YAG laser welding onto the second base plate **18** through the first support member **19***a*.

Subsequently, the polarization synthesizing module **59** including the prism **5**, the half-wave plate **6** and the PBC **7** as the integral unit on the whole, is aligned and fixed onto the second base plate **18**. In this aligning step of the polarization synthesizing module **59**, the polarization synthesizing module **59** is aligned in the X- Y- and Z-axis directions and rotated about angle θ of the central axis C**1** (see FIGS. **4**(A) to **4**(*c*)) of the holder member **14** so that an optical intensity of the beams coupled to the fiber is maximized by use of a positioning optical fiber collimator. The polarization synthesizing module **59** is adjusted in its position and then positioned about the central axis C**1** of the holder member **14** by rotating the holder member **14** about the central axis C**1** so that both of the first laser beams **K1** entering the first input part **7***a* and the second laser beam **K2** entering the second input part **7***b*, exit the output part **7***c*.

The polarization synthesizing module **59** is positioned in the Z-axis direction in a way that adjust the degree of how much the laser beams K1, K2 outputted from the PBC **7** overlap with each other on the X-Y plane. For example, the laser beams K1, K2 may completely overlap with each other, or positions of their beam spots may also be shifted. In the latter case, if the laser beams K1, K2 have different optical intensities, the optical fiber **8** is aligned so as to receive a larger quantity of laser beam having the smaller optical intensity, thus equalizing the optical intensities of the laser beams K1, K2 entering the optical fiber **8**. The degree of polarization can be, it is preferable, thereby sufficiently decreased.

The holder member **14** is fixed by the YAG laser welding in the position determined in the aligning step described above onto the second base plate **18** through the second support member **19***b*.

Subsequently, the first base plate **17** is fixed by soldering onto the cooling device **20** fixed beforehand onto a bottom plate of the package **1**.

Then, the semiconductor laser device **2** and the monitor-oriented photo diode **3** are electrically connected to leads (not shown) of the package **1** through a metal wires (unillustrated).

Next, a cover **1***c* is covered over the upper portion of the package **1** in an inert gas (e.g., N.sub.**2**, Xe) atmosphere, and a peripheral edge portion thereof is resistance-welded, thereby hermetically sealing it.

Subsequently, the second lens **16** is aligned within the X-Y plane and in the Z-axis direction and thus fixed to the first flange **1***a* of the package **1**. In this step, the first flange **1***a* is fixed by the YAG laser welding in such a position that the beam emerging from the second lens **16** is parallel to the central axis of the flange **1***a* of the package **1**.

Finally, the optical fiber **8** is aligned and then fixed. In this step, the metallic slide ring **22** is fixed to the side edge of the second lens holding member **21**. The slide ring **22** is adjusted in its position within the plane (the X-Y plane) perpendicular to the optical axis of the optical fiber **8** at the edge surface of the second lens holding member **21**, and is thereafter fixed by the YAG laser welding at a boundary therebetween. The ferrule **23** for holding the optical fiber **8** is fixed by the YAG laser welding to an interior of the slide ring **22** in such a position that the beam emission from the optical fiber **8** is maximized. On this occasion, the optical fiber **8** is aligned taking a power balance of the plurality of laser beams to be synthesized into consideration. The position of the optical fiber **8** in the optical-axis direction (the z-axis direction) is thereby fixed.

Now, the semiconductor laser device **2** used for the semiconductor laser module in accordance with the first embodiment of the present invention will be explained. FIGS. **8**(A) to **8**(C) are explanatory views showing the configuration of the semiconductor laser device **2** used for the semiconductor laser module of the present invention. FIG. **9** is an explanatory view showing another example of the semiconductor laser device **2**. Note that FIGS. **8**(B) and **8**(C) are the sectional views taken along the line a-a in FIG. **8**(A).

As shown in FIG. **8**(A), the semiconductor laser device **2** is configured such that a lamination structure **25** is formed on a substrate **24** composed of a predetermined semiconductor by executing a predetermined semiconductor epitaxial crystal growth on the basis of a known epitaxial growth method such as an organic metal vapor phase growth method, a liquid phase method, a molecular beam epitaxial growth method and a gas source molecular beam epitaxial growth method, thereafter a lower electrode **26** is provided on an undersurface of the substrate **24**, an upper electrode **27** is provided on an upper surface of the lamination structure **25**, a predetermined cavity length L3 is obtained by cleavage, further a low-reflection layer **28** (a reflectance is, e.g., 5% or smaller) is formed on one cleavage surface (the front edge surface **2***a*), and a high-reflection layer **29** (a reflectance is, e.g., 90% or larger) is formed on the other cleavage surface (the rear edge surface **2***b*).

As shown in FIG. **8**(B), the lamination structure **25** on the substrate **24** is, for instance, a BH (buried hetero) structure, wherein n-InP clad layer **31**, an active layer **32** composed of, e.g., GaInAsP and an p-InP clad layer **33** are sequentially laminated on the substrate composed of e.g., n-InP, and further an upper buried layer **34** composed of, e.g., p-InP and a cap layer **35** composed of, e.g., p-GaInAsP are laminated on the p-InP clad layer **33**. Then, the upper electrode **27** is provided on this cap layer **35**, and the lower electrode **26** is provided on the undersurface of the substrate **24**.

The n-InP clad layer **31**, the active layer **32** and the upper buried layer **34**, are processed into two steaks of stripes in parallel with each other with a space of 40–60 μm, and, for example, a p-InP layer **36** and an n-InP layer **37** are laminated in this sequence on its side surfaces, thereby forming a constricted portion for letting the electric current through to the active layer **32**.

The active layer **32** involves, for instance, a compressive strain quantum well structure, wherein a lattice mismatching rate with respect to the substrate **24** is 0.5% or larger but is not larger than 1.5%. Besides, it is advantageous in terms of gaining a higher output to take a multi quantum well structure in which the number of wells is about 5. Further, if the strain quantum well structure adopts a strain compensation structure in which a barrier layer thereof takes a tensile strain opposite to the strain of the well layer, whereby the lattice match condition can be equivalently met, and a further higher value of the grating matching degree of the well layer, can be tolerated.

According to the first embodiment, the light emitting portions consisting of the n-InP clad layer **31**, the GRIN-SCH-MQW active layer **32** and the p-InP clad layer **33** are formed extending in the form of stripes in the direction vertical to the sheet surface in FIG. **8**, and these portions are called the stripes **9** and **10**, respectively.

Next, a method of manufacturing the semiconductor laser device **2** having the structure described above will be explained.

To begin with, the n-InP clad layer **31**, the active layer **32**, the p-InP clad layer **33** are laminated in this sequence on the substrate **24** by the known epitaxial growth method such as the organic metal vapor phase growth method, the liquid phase method, the molecular beam epitaxial growth method and the gas source molecular beam epitaxial growth method.

Subsequently, two pieces of masks arranged in parallel with each other with the space of 40–60 μm are provided on the p-InP clad layer **33**. Thereafter, some portions of the p-InP clad layer **33**, the active layer **32**, the n-InP clad layer **31** and the substrate **24**, are dissolved by use of a predetermined etchant (etching liquid), the p-InP layer **36** and the n-Inp layer **37** are laminated in this sequence on the stripes, thereby forming the constricted portion for letting the electric current through to the active layer **32**.

Subsequently, the upper buried layer **34** is crystal-grown with epitaxial growth method.

Further, the cap layer **35** is laminated on the upper buried layer **34**.

Next, the upper electrode **27** is formed on the upper surface of the cap layer **35**, and the lower electrode **26** is formed on the undersurface of the substrate **24**.

Thereafter, the cavity length L3 is obtained by the cleavage of the substrate. Further, the low-reflection layer **28** is formed on one cleavage surface (the front edge surface **2***a*), and the high-reflection layer **29** is formed on the other cleavage surface (the rear edge surface **2***b*).

In the thus manufactured semiconductor laser device **2**, the side of the upper electrode **27** is bonded by AuSn-soldering to the heat sink **58** shown in FIG. **1**(B). Then, the laser oscillations occur simultaneously at the two stripes when supplied with the electric current from outside via the upper electrode **27** (on the p-side in the first embodiment) and the lower electrode **26** (on the n-side in the first embodiment), and the two fluxes of outgoing beams from the low-reflection layer **28** are multiplexed by the PBC **7** described above and used for an application.

Supposing herein that the two stripes have absolutely the same characteristic, a threshold current of the semiconductor laser device **2** in the first embodiment is twice the threshold current of one single stripe, and the total optical output is twice the optical output of the single stripe. Namely, the semiconductor laser device **2** as a whole obtains approximately a 2-fold optical output with the drive current that is approximately twice the drive current per stripe, and a slope efficiency of the semiconductor laser device **2** is substan-

tially the same as that of the semiconductor laser device **1** having one single stripe.

Note that the first embodiment discussed above has exemplified the structure in which the two stripes are simultaneously driven. As shown in, for example, FIG. **8**(C), however, a separation trench **38** having a depth extending from the upper electrode **27** down to the lower clad layer **30**, maybe formed between the two stripes, and the surface of this separation trench **38** is covered with an insulation layer **39**, whereby the two stripes can be electrically separated. If a lower electrode **26** sided portion of the semiconductor laser device **2** described above is bonded by AuSn-soldering to the unillustrated heat sink, the drive currents supplied to the two stripes can be independently controlled, thereby facilitating randomization of the polarization planes of the laser beams emitted from the optical fiber **8**. In this case, at least one of the positive electrode side and the negative electrode side of each of the two stripes may be electrically insulated.

Note that the semiconductor laser device **2**, when structured as shown in FIG. **8**(C), may be used by applying the drive current to only one stripe, and may also be used by applying, if the active layer of one stripe fall into an abnormal state, the drive current to the other stripe instead of the one stripe. In this case, one stripe is configured as a redundant system, and hence the semiconductor laser device **2** comes to have a longer product life-span.

Further, when used in a way such that the upper electrode **27** sided portion is bonded to the heat sink **58**, an electrode pattern corresponding to the upper electrode **27** is formed beforehand on the heat sink **58** side, whereby those two stripes can be independently driven.

Further, the semiconductor laser device **2** in the first embodiment discussed above has been exemplified as having the InP-series BH (buried hetero) structure. However, there may also be used the semiconductor laser device **2** of, e.g., a GaAs based ridge waveguide type as shown in FIG. **9**. As shown in FIG. **9**, this semiconductor laser device **2** has a structure in which an n-type lower clad layer **41**, an active layer **42**, a p-type upper clad layer **43**, an insulation layer **44**, a p-GaAs layer **45** are laminated on a substrate **40** made of n-GaAs, and two ridges are formed. An upper electrode (p-type electrode) **46** is formed over the insulation layer **44** and the p-GaAs layer **45**. A lower electrode (n-type electrode) **47** is formed on an undersurface of the substrate **40**.

The ridges are formed extending in stripes in the direction vertical to the sheet surface in FIG. **9**. Each of the active layer streaks **42** just under along the ridges emits light. These luminescent layer streaks are called the stripes **9** and **10**, respectively. Of course, a InP ridge type LD can be used in this embodiment.

Furthermore, the first embodiment has exemplified the Fabry-Perot semiconductor laser device **2** as the basic structure of the semiconductor laser device **2**. In addition, the semiconductor laser device **2** may include a wavelength selecting element such as DFB, DBR and so on as will be mentioned later on. When using this type of semiconductor laser device **2**, the optical output with the oscillation wavelength stabilized can be obtained without using the optical fiber with the FBG.

Second Embodiment

FIG. **10** is an explanatory diagram schematically showing a configuration of a semiconductor laser module M2 in accordance with a second embodiment of the present invention. As shown in FIG. **10**, according to the second embodiment, incident surfaces of the PBC **7** upon which the first and second laser beams K1, K2 are incident are inclined in a wedge-like shape so that the first laser beam K1 travels as a normal ray in the axial-line direction of the optical fiber **8**. Other than this point, this embodiment is substantially the same as the semiconductor laser module in the first embodiment.

According to the second embodiment, the first laser beam K1 as the normal ray travels in the axial-line direction of the optical fiber **8**, and hence there is no necessity of providing the prism **5** between the half-wave plate **6** and the first lens **4**, thereby making it possible to simplify the configuration.

Moreover, the length of the semiconductor laser module M2 in the optical-axis direction can be reduced, and it is therefore feasible to decrease the influence of the warp of the package on the optical output characteristic in a high-temperature state.

Note that the half-wave plate **6** and the PBC **7**, which are fixed to the same holder member **14**, may be structured as a polarization synthesizing module in order to facilitate the angle adjustment about the central axis also in the second embodiment.

Third Embodiment

FIG. **11** is an explanatory diagram schematically showing a configuration of a semiconductor laser module **M3** in accordance with a third embodiment of the present invention. As shown in FIG. **11**, according to the third embodiment, the semiconductor laser device **2** and the first lens **4** are disposed with tilts at predetermined angles to the axial-line direction so that the first laser beam K1, after traveling through a first lens **4**, travels as the normal ray in the axial-line direction of the optical fiber **8**. Other than this point, this embodiment is substantially the same as the semiconductor laser module in the first embodiment.

According to the third embodiment, the first laser beam K1 travels as the normal ray in the axial-line direction of the optical fiber **8**, and hence there is no necessity of providing the prism **5** between the half-wave plate **6** and the first lens **4**, thereby making it possible to simplify the configuration. Further, only one side of the PBC **7** may be polished, and hence the polishing can be more simplified than in the second embodiment.

Moreover, the length of the semiconductor laser module **M3** in the optical-axis direction can be reduced, and it is therefore feasible to decrease the influence of the warp of the package on the optical output characteristic in the high-temperature state.

Note that the half-wave plate **6** and the PBC **7**, which are fixed to the same holder member **14**, may be structured as a polarization synthesizing module in order to facilitate the angle adjustment about the central axis also in the third embodiment.

Each of the semiconductor laser modules **M1** to **M3** in the first through third embodiments discussed above is capable of emitting the laser beams with high output, small degree of polarization and stabilized wavelength, and can be therefore used as the pumping light source for the erbium-doped optical amplifier or the Raman amplifier.

Fourth Embodiment

FIG. **12** is a fragmentary perspective view showing a polarization synthesizing module **60** in accordance with a fourth embodiment of the present invention, used for a

semiconductor laser module in the present invention and having a different configuration from that of the polarization synthesizing module **59** shown in FIG. **4**. FIG. **13** is a side sectional view showing the polarization synthesizing module **60** shown in FIG. **12**. Note that, the same members as those in the polarization synthesizing module **59** are marked with the same symbols, and their repetitive explanations are omitted.

As shown in FIGS. **12** and **13**, the polarization synthesizing module **60** in the fourth embodiment includes a holder member **61** formed with a groove **61***a* (a accommodation space) extending in the longitudinal direction, first and second adjustment sheets **62**, **63** so disposed as to be fitted into the groove **61***a* of the holder member **61**, the prism **5** disposed on the first adjustment sheet **62**, the PBC **7** disposed on the second adjustment sheet **63**, a half-wave plate holder **64** so disposed as to be fitted into the groove **61***a* of the holder member **61**, the half-wave plate **6** held by the half-wave plate holder **64**, and a plate-like bottom cover **65** fixedly inset in a stepped portion **61***b* formed on an aperture side of the groove **61***a* of the holder member **61**.

The holder member **61**, the half-wave plate holder **64** and the bottom cover **65** are made of a material (e.g., Kovar) that can be YAG-laser-welded.

An upper portion of the half-wave plate **6** is metalized, and an upper portion of the half-wave plate holder **64** is gold-plated. The upper portion of the half-wave plate **6** is fixed by soldering to the upper portion of the half-wave plate holder **64**.

The first and second adjustment sheets **62**, **63** are formed of a material deformable enough to facilitate positioning of the prism **5** and the PBC **7** as well. The first and second adjustment sheets **62**, **63** may be composed of a flexible member such as a soft metal (In, and so on) and a solder sheet (Sn-Pb, and so forth), and of a resilient member such as a resin.

The polarization synthesizing module **60** is also fitted with first and second stoppers **66**, **67** fixed by the YAG laser welding to both side edges of the groove **61***a* of the holder member **61**. As shown in FIG. **13**, the first stopper **66** and the half-wave plate holder **64** hold the first adjustment sheet **62** sandwiched in therebetween and thus function as a slide stopper for the first adjustment sheet **62**. Further, the second stopper **67** and the half-wave plate holder **64** hold the second adjustment sheet **63** sandwiched in therebetween and thus function as a slide stopper against the second adjustment sheet **63**.

Note that the first and second stoppers **66**, **67** may be formed beforehand integrally with the holder member **61**.

Further, note that the first and second stoppers **66**, **67** may be formed of transparent materials e.g. glass, resin. And lens, prism **5**, PBC **7**, or half wave plate **6** can be used as the stoppers **66**, **67**.

Next, a method of assembling the polarization synthesizing module **60** in the fourth embodiment will be explained. At first, the first and second stoppers **66**, **67** are fixed by the YAG laser welding to both of the side edges of the groove **61***a* of the holder member **61**.

Subsequently, the half-wave plate **6** is secured by soldering to the half-wave plate holder **64**.

Then, the half-wave plate holder **64** holding the half-wave plate **6** is fixed by the YAG laser welding to the groove **61***a* of the holder member **61**. On this occasion, the half-wave plate holder **64** is positioned so that the first and second adjustment sheets **62**, **63** are respectively fitted in between the first and second stoppers **62**, **63** and the half-wave plate holder **64**.

Next, the first adjustment sheet **62** is so disposed as to be fitted into the groove **61***a* of the holder member **61** between the first stopper **66** and the half-wave plate holder **64**. Further, the second adjustment sheet **63** is so disposed as to be fitted into the groove **61***a* of the holder member **61** between the second stopper **67** and the half-wave plate holder **64**.

Subsequently, the prism **5** is placed on the first adjustment sheet **62**, and the PBC **7** is placed on the second adjustment sheet **63**.

Then, the bottom cover **65** is set in the stepped portion **61***b* formed on the aperture side of the groove **61***a* of the holder member **61**. The surfaces of the prism **5** and the PBC **7** are brought into contact with and pressed against an undersurface **65***a* of the bottom cover **65**. The first and second adjustment sheets **62**, **63** are thereby deformed, and the prism **5** and the PBC **7** are positioned in their predetermined positions.

Finally, the bottom cover **65** is fixed by the YAG laser welding to the holder member **61**.

In this polarization synthesizing module **60**, the surfaces of the prism **5** and the PBC **7** are brought into contact with and pressed against the undersurface **65***a* of the bottom cover **65** and positioned with the aid of the deformations of the first and second adjustment sheets **62**, **63**. The undersurface **65***a* of the bottom cover **65** is formed flat with a higher working precision than the surface of the groove **61***a*. Accordingly, the light incident surfaces of the prism **5** and of the PBC **7**, the top of which have been brought into contact with the undersurface **65***a* of the bottom cover **65**, are positioned precisely perpendicular with respect to the undersurface **65***a* of the bottom cover **65**, whereby a rotational direction θ about the optical axis can be positioned with high accuracy.

Considering from this point, it is feasible that the working precision of the undersurface **65***a* of the bottom cover **65** where the surface of the prism **5** and PBC are brought into contact, may fulfil at least one of conditions below of the planar roughness;

maximum height, Rmax=$\leqq$10 μm,

center-line-average-roughness, Ra=$\leqq$5 μm,

average roughness measured at 10 points, Ra=$\leqq$10 μm.

Note that the first and second adjustment sheets **62**, **63** can be integrated to one sheet.

Note that the prism **5** and the PBC **7** may be gold-plated and fixed by soldering directly to the groove **61***a* of the holder member **61**. In this case, the first and second adjustment sheets **62**, **63** are not required, however, it is preferable that the working surface of the groove **61***a* be formed accurately.

Fifth Embodiment

The first and second stripes **9**, **10** of the semiconductor laser device **2** described above are formed to extend in parallel to each other in the longitudinal direction. The first and second stripes **9**, **10** may, however, for instance, be formed to be inclined to each other as shown in FIG. **14**. Referring to FIG. **14**, the laser beams are emitted toward the right side, and the space between the stripes **9** and **10** becomes narrower as it gets closer to the right side edge. In this case, the two first and second laser beams K1, K2 emitted from the two stripes **9**, **10** intersect each other at a comparatively short distance from the semiconductor laser device **2**, and, after traveling through the first lens **4**, split (which implies that a divergent width D' becomes suffi-

ciently large in FIG. **2**). Therefore, a required propagation distance (L in FIG. **2**) decreases, and hence the length of the semiconductor laser module M in the optical-axis direction can be reduced.

Note that the propagation distance L can be likewise reduced even when emitting the laser beams in the leftward direction.

Sixth Embodiment

FIGS. **15**(A) to **15**(C) show a semiconductor laser device **68** in accordance with a sixth embodiment used for the semiconductor laser module in accordance with the embodiments of the present invention and having a different configuration from the semiconductor laser device **2** shown in FIGS. **8**(A) to **8**(C). FIGS. **15**(B) and **15**(C) are sectional views taken along the line b-b and the line c-c in FIG. **15**(A), respectively.

As shown in FIGS. **15**(A) through **15**(C), the semiconductor laser device **68** in the sixth embodiment has a structure in which an n-InP buffer layer **70** serving as both an n-Inp buffer layer and a lower clad layer, a GRIN-SCH-MQW (distribution refractive index isolating/trapping multi quantum well) active layer **71**, a p-InP upper clad layer **72**, a p-InP buried layer **73** and an InGaAsP cap layer **74**, are laminated sequentially on a surface **(100)** of an n-InP substrate **69**.

Within each of the p-InP upper clad layer **72** of the two stripes, p-InGaAs diffraction gratings **75** each having a thickness on the order of 20 nm are formed periodically at a pitch of approximately 230 nm. The diffraction gratings **75** serve to adjust a center wavelength of the laser beams to a predetermined wavelength, e.g. in the 1.48 μm band. Upper portions of the p-InP upper clad layer **72** containing the diffraction grating **75**, the GRIN-SCH-MQW active layer **71** and the n-InP buffer layer **70**, are worked in a mesa stripe. Both sides of the mesa strip are embedded in a p-InP blocking layer **76** and an n-InP blocking layer **77** that are formed as current blocking layers. Further, a p-type electrode **78** is-formed on an upper surface of the InGaAsP cap layer **74**, and an n-type electrode **79** is formed on an undersurface of the n-InP substrate **69**.

A first reflection layer **80** having a reflectance as high as 80% or greater is formed on a beam reflection edge surface as one edge surface of the semiconductor laser device **68** in the longitudinal direction. A second reflection layer **81** having a reflectance as low as 5% or less is formed on a beam output edge surface as the other edge surface thereof. The beams generated within the GRIN-SCH-MQW active layer **71** of an optical resonator formed between the first and second reflection layers **80**, **81**, are reflected by the first reflection layer **80** and exit as laser beams via the second reflection layer **81**.

The semiconductor laser device **68**, if used as a pumping light source for, e.g., the Raman amplifier, has its oscillation wavelength λ_0 on the order of 1300 to 1550 nm and a cavity length L_R that is set from not less than 800 μm to not more than 3200 μm.

Note that, a mode spacing $\Delta\lambda$ of the longitudinal mode generated by the resonator of the semiconductor laser device is generally expressed by the following formula.

Namely;

$$\Delta\lambda=\lambda_0^2/(2\cdot n\cdot L_R)$$

Herein, if the oscillation wavelength $\lambda 0$ is set to 1480 μm and an equivalent refractive index is set to 3.5, when the cavity length is 800 μm, the longitudinal mode spacing $\Delta\lambda$ is approximately 0.39 nm. When the cavity length is 3200 μm, the longitudinal mode spacing $\Delta\lambda$ is approximately 0.1 nm. That is, as the cavity length is set larger, the longitudinal mode spacing $\Delta\lambda$ becomes narrower.

The diffraction grating **75** selects the longitudinal mode with a Bragg wavelength thereof. A wavelength selecting characteristic of this diffraction grating **75** is given as an oscillation wavelength spectrum **82** shown in FIG. **16**. As shown in FIG. **16**, a contrivance in accordance with the sixth embodiment is that a plurality of oscillation longitudinal modes exist within a $FWHM_h$ of the oscillation wavelength spectrum by the semiconductor laser device with the diffraction gratings **75**. The conventional semiconductor laser device, if the cavity length L_R is set to 800 μm or larger, is difficult to achieve the single longitudinal mode oscillations. Therefore, the semiconductor laser device having the above cavity length L_R has not been used. The semiconductor laser device **68** in the sixth embodiment, however, with the cavity length L_R positively set to 800 μm or larger, emits the laser beams, in which the plurality of oscillation longitudinal modes are contained within the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum. Referring to FIG. **16**, the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum contains three oscillation longitudinal modes **83***a* to **83***c*.

When using the laser beams having the plurality of longitudinal modes, a higher laser output value than in the case of using the laser beams of the single longitudinal mode can be obtained restraining the peak value of the laser emission. For example, the semiconductor laser device **68** exemplified in the sixth embodiment has a mode profile as shown in FIG. **17**(B) and is capable of obtaining a high laser output with a low peak value. By contrast, FIG. **17**(A) shows a mode profile of the single longitudinal mode oscillations having a high peak value by the semiconductor laser device in the case of obtaining the same laser output.

Herein, in the case of using the semiconductor laser device as the pumping light source for the Raman amplifier, it is preferable that pumping beam output power be increased in order to enhance a Raman gain. If a peak value thereof is high, however, the stimulated Brillouin scattering occurs, and there arises a problem in that the noises rise. With the occurrence of the stimulated Brillouin scattering, when obtaining the same laser output power including a threshold value Pth that triggers the occurrence of the stimulated Brillouin scattering, as shown in FIG. **17**(B), the plurality of oscillation longitudinal modes are given, and its peak value is restrained, thereby making it feasible to obtain the high pumping beam output power having a plurality of longitudinal modes respectively within the threshold value Pth of the stimulated Brillouin scattering. As a result, a high Raman gain can be acquired.

Further, as shown in FIG. **16**, the wavelength spacing (mode spacing) $\Delta\lambda$ between the oscillation longitudinal modes **83***a* to **83***c* is set to 0.1 nm or larger. This is because when the semiconductor laser device **68** is used as the pumping light source for the Raman amplifier, if the mode spacing $\Delta\lambda$ is 0.1 nm or less, there might be a high possibility in which the stimulated Brillouin scattering occurs. As a consequence, it is concluded preferable from the above formula of the mode spacing $\Delta\lambda$ that the cavity length L_R be 3200 μm or less.

It is desirable that the number of the oscillation longitudinal modes contained within the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum is three or more. It is because when the semiconductor laser device is used as the pumping light source for the Raman amplifier, there is a polarization

dependency that the Raman amplification occurs in a state where the polarizing direction of the signal light is set to be coincident with the polarizing direction of the pumping beam, and hence there is a necessity of obtaining the pumping beam with no polarization by polarization-synthesizing the pumping beams emitted from the semiconductor laser device through the polarization maintaining fiber. Generally, as the number of oscillation longitudinal modes increases, a necessary length of the polarization maintaining fiber can be decreased. Particularly when there are four or five oscillation longitudinal modes, the necessary length of the polarization maintaining fiber abruptly decreases. Accordingly, the length of the polarization maintaining fiber used in the Raman amplifier can be reduced by setting the number of oscillation longitudinal modes to three or more and particularly four or more, thereby simplifying and downsizing the Raman amplifier.

Further, the rise in the number of oscillation longitudinal modes leads to a decreased coherent length, and the degree of polarization decreases due to depolarization, with the result that the polarization dependency can be eliminated. This also makes it possible to simplify and downsize the Raman amplifier.

Herein, if the oscillation wavelength spectral width is too large, a multiplexing loss by a wavelength synthesizing coupler increases, and the noises and the gain fluctuations occur due to a wavelength behavior within the oscillation wavelength spectral width. Therefore, the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82** is set to 3 nm or less and preferably to 2 nm or less.

Moreover, the semiconductor laser module using the fiber Bragg grating has a large relative intensity noise (RIN) due to a resonance between the FBG and the beam reflection surface, and there might be a case where the stable Raman amplification can not be effected. In contrast with this, the semiconductor laser module using the semiconductor laser device **68** in the sixth embodiment has no necessity of using the FBG, and the laser beams emerging from the second reflection layer **81** can be used directly as the pumping light source for the Raman amplifier. Hence, the relative intensity noises decrease with the result that a fluctuation in the Raman gain becomes small, and the stable Raman amplification can take place.

Moreover, the semiconductor laser module using the FBG is required to have the optical coupling between the optical fiber containing the FBG and the semiconductor laser device, and therefore needs the alignment of the optical axis when assembling the semiconductor laser device. This is time-consuming and takes a labor. In contrast with this, the semiconductor laser device **68** in the sixth embodiment needs the alignment of the optical axis not for the resonator but for the optical output and is therefore easier to assemble.

Further, the semiconductor laser module using the FBG requires the mechanical coupling within the resonator, and consequently there arises a case in which the oscillation characteristic of the laser changes due to the vibrations or the like. By contrast, the semiconductor laser device **68** in the sixth embodiment has no change in the laser oscillation characteristic due to the mechanical vibrations or the like, and is capable of obtaining the stable optical output.

According to the sixth embodiment, the semiconductor laser device **68** makes the wavelength selection with the aid of the diffraction gratings **75**, and sets the oscillation wavelength to 1300 to 1500 μm and the cavity length L_R to 800 to 3200 μm, thereby emitting the laser beams having the plurality of oscillation longitudinal modes, preferably four or more oscillation longitudinal modes within the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82**. As a result, the stable and high Raman gain can be obtained without the occurrence of the stimulated Brillouin scattering in the case of being used as the pumping light source for the Raman amplifier.

Further, the optical coupling of the semiconductor laser device to the optical fiber containing the FBG is not attained within the resonator, thereby facilitating the assembly and making it feasible to avoid the unstable emission derived from the mechanical vibrations or the like.

Seventh Embodiment

FIGS. **18**(A) to **18**(C) are vertical sectional views each showing a configuration of the semiconductor laser device in the longitudinal direction according to a seventh embodiment.

In the sixth embodiment discussed above, there are provided the plurality of longitudinal modes within FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82** by increasing the cavity length L_R. In contrast with this contrivance, according to the seventh embodiment, the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82** is changed by varying a grating length LG of the diffraction grating **75** or a coupling coefficient, whereby the number of longitudinal modes within FWHM $\Delta\lambda_h$ becomes relatively plural.

As shown in FIG. **18**(A), a semiconductor laser device **84***a* is different in layout of the diffraction gratings **75** from the semiconductor laser device **68** in the sixth embodiment, and has a different reflectance of the second reflection layer **81**. The configurations of other components are substantially the same as those of the semiconductor laser device **68**, and the same components are marked with the same reference numerals, of which the repetitive explanations are omitted.

The diffraction gratings **75** are formed by a predetermined length LG**1**, extending from the second reflection layer **81** having a beam reflectance of as low as 2% or less, suitably 1% or less, more suitably 0.2% or less toward the first reflection layer **80** having a beam reflectance of as high as 80% or greater, but are not formed on the p-InP spacer layer **72** out of the predetermined length LG**1**.

Further, FIG. **18**(B) is a vertical sectional view showing in the longitudinal direction a configuration of a semiconductor laser device **84***b* defined as a modified example of the seventh embodiment. This semiconductor laser device **84***b* has the diffraction gratings **75** provided on the side of the first reflection layer **80**, in which the beam reflectance of the first reflection, layer **80** is set to be low. Namely, the diffraction gratings **75** are provided to a predetermined length LG**2**, extending from the first reflection layer **80** having a beam reflectance of as low as 2% or less toward the second reflection layer **81** having a beam reflectance of as low as 1 to 5%, but are not formed on the p-InP spacer layer **72** out of the predetermined length LG**2**.

Moreover, FIG. **18**(C) is a vertical sectional view showing in the longitudinal direction a configuration of a semiconductor laser device **84***c* defined as another modified example of the seventh embodiment. This semiconductor laser device **84***c* simultaneously adopts the layouts of the diffraction gratings **75** shown in FIG. **18**(A) and of the refracting gratings **75** shown in FIG. **18**(B).

Namely, the semiconductor laser device **84***c* has the diffraction gratings **75** formed by a predetermined length LG**3**, extending from the second reflection layer **81** having a beam reflectance of as low as 2% or less toward the first reflection layer **80** having a beam reflectance of as low as 2% or less, and the diffraction gratings **75** formed by a prede-

termined length LG4, extending from the first reflection layer **80** toward the second reflection layer **81**.

The FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82** shown in FIG. **16** can be varied by changing the predetermined lengths of the diffraction gratings **75** shown in FIG. **18** even if the mode spacing $\Delta\lambda$ of the oscillation longitudinal modes is a fixed value.

That is, it is effective to reduce the length of the diffraction gratings **75** for increasing the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82**. Hence, as shown in the seventh embodiment, the diffraction gratings **75** are not formed over the entire length of the resonator (GRIN-SCH-MQW active layer **71**) but are formed to a segment of this cavity length.

In this case, a phase oscillation condition might deviate depending on the positions of the refracting gratings **75** with respect to the resonator, and this deviation might induce a decline of the laser oscillation characteristic. Hence, as shown in FIG. **18**(A), when the diffraction gratings **75** are formed extending from the second reflection layer **81** up to a point halfway along the resonator toward the first reflection layer **80**, the second reflection layer **81** has the reflectance of as low as 2% or less, and the first reflecting layer **80** has the reflectance of as high as 80% or greater. Further, as shown in FIG. **18**(B), when the diffraction gratings **75** are formed extending from the first reflection layer **80** up to a point halfway along the resonator toward the second reflection layer **81**, the first reflection layer **80** has the reflectance of as low as 2% or less, and the second reflecting layer **81** has the reflectance of as low as 1 to 5%. Moreover, as shown in FIG. **18**(C), when the refracting gratings **75** are formed on the sides of the second and first reflection layers **81** and **80** respectively, both of the second and first reflection layers **81**, **80** have the low reflectance on the order of 2% or less.

Further, as shown in FIG. **18**(A), when the diffraction gratings **75** are formed on the side of the second reflection layer **81**, it is preferable that the reflectance of the diffraction grating **75** itself be set comparatively low. As shown in FIG. **18**(B), when the diffraction gratings **75** are formed on the side of the first reflection layer **80**, it is preferable that the reflectance of the diffraction grating **75** itself be set comparatively high. Moreover, as shown in FIG. **18**(C), when the diffraction gratings **75** are formed on both sides of the first and second reflection layers **80**, **81**, the reflectance of the diffraction grating **75** itself provided on one side is set comparatively low, and the reflectance of the diffraction grating **75** itself formed on the other side is set comparatively high. With the settings described above, it is feasible to reduce the influence of the first and second reflection layers **80**, **81** upon the Fabry-Perot resonator in such a way that the wavelength selection characteristic of the diffraction gratings **75** is satisfied.

To be more specific, the semiconductor laser device shown in FIG. **18**(A) is 1300 μm in the cavity length L_R, 50 μm in the grating length of the diffraction gratings **75** and 0.125 in the product K*LG of the coupling coefficient K and FBG length LG. When the diffraction gratings **75** described above are applied, the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82** is approximately 2 nm, and the FWHM $\Delta\lambda_h$ can contain three to eight oscillation longitudinal modes.

Further, referring to FIGS. **18**(A) through **18**(C), the diffraction gratings **75** are provided on the side of the second reflection layer **81** or the first reflection layer **80**, or on the both sides of the second and first reflection layers **81**, **80**. The diffraction gratings **75** may, however, be provided to a segment of the cavity length along the GRIN-SCH-MQW active layer **71** without being limited to the above layouts. It is, however, desirable that the reflectance of the diffraction grating **75** be taken into consideration.

According to the seventh embodiment, the length of the diffraction gratings **75** is set segmental to the cavity length L_R, and the grating length LG and the coupling coefficient K*LG of the diffraction gratings **75** are properly varied, thereby obtaining the preferable FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82**. Then, the laser beams having the plurality of oscillation longitudinal modes within this FWHM $\Delta\lambda_h$ can be obtained, and the semiconductor laser device exhibiting the same operation effects as those in the sixth embodiment can be actualized.

Eighth Embodiment

FIG. **19** is a vertical sectional view showing in the longitudinal direction a configuration of the semiconductor laser device in accordance with an eighth embodiment of the present invention.

The grating period of the diffraction gratings **75** is fixed in the sixth and seventh embodiments discussed above. However, the eighth embodiment involves the use of chirped gratings in which the grating period of the diffraction gratings **75** is periodically changed, thereby causing a fluctuation in the wavelength selection characteristic of the diffraction gratings **75** and expanding the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82**. Then, the number of the longitudinal modes within the FWHM $\Delta\lambda_h$ is made relatively plural.

As shown in FIG. **19**, the semiconductor laser device **85** has the diffraction gratings **75** categorized as the chirped gratings in which the grating period of the diffraction gratings **75** is periodically changed. The configurations of other components are the same as those of the semiconductor laser device **68** in the sixth embodiment, and the same components are marked with the same symbols, of which the repetitive explanations are omitted.

FIG. **20** is a graph showing the periodic change of the grating period of the diffraction gratings **75**. As shown in FIG. **20**, the refracting gratings **75** have such a structure that an average period is 230 nm, and a periodic fluctuation (deviation) on the order of ±0.15 nm is repeated with a period C. The reflection band of the diffraction gratings **75** has a FWHM of approximately 2 nm due to the periodic fluctuation of ±0.15 nm, and about three to six oscillation longitudinal modes can be thereby given within the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum **82**.

In the eighth embodiment discussed above, the chirped gratings are formed having a length equal to the cavity length L_R. The diffraction gratings **75** as the chirped gratings may, however, be disposed to a segment of the cavity length L_R as in the seventh embodiment without being limited to the layout given above. Namely, the chirped gratings exemplified in the eighth embodiment discussed above may be applied to the seventh embodiment.

Further, the eighth embodiment involves the use of the chirped gratings in which the grating period is changed with the fixed period C. The grating period is not, however, restricted to this period C and may also be changed at random between a period **Λ1**(230 nm+0.15 nm) and a period **Λ2**(230 nm-0.15 nm).

Moreover, as shown in FIG. **21**(A), diffraction gratings **75a** with the period **Λ1** and the period **Λ2** repeated one by one alternately may be given a period fluctuation. Further, as shown in FIG. **21**(B), diffraction gratings **75b** with the period **Λ1** and the period **Λ2** each repeated a plurality of

times alternately may be given a period fluctuation. Still further, as shown in FIG. **21**(C), diffraction gratings **75***c* having a plurality of consecutive periods Λ**1** and a plurality of consecutive periods Λ**2** may be given a period fluctuation. Moreover, the diffraction gratings may be laid out with complementing a period having a different discrete value between the period Λ**1** and the period Λ**2**.

In the eighth embodiment, the diffraction gratings **75** provided in the semiconductor laser device are formed as the chirped gratings and so on, thereby giving the period fluctuation on the order of ±0.05 to 0.2 nm with respect to the average period. The FWHM of the reflection band is thereby set to a preferable value, the FWHM $\Delta\lambda_h$ of the oscillation wavelength spectrum is finally determined, and the laser beams with a plurality of oscillation longitudinal modes contained within the FWHM $\Delta\lambda_h$ are outputted. It is therefore possible to actualize the semiconductor laser device having the same operation effects as those in the sixth or seventh embodiment.

Ninth Embodiment

According to the semiconductor laser devices in the sixth through eighth embodiments, the wavelengths selected by the diffraction gratings **75** formed in the two stripes are substantially the same. By contrast, according to the semiconductor laser device in accordance with a ninth embodiment of the present invention, the wavelengths selected by the diffraction gratings **75** formed in the two stripes are selectively set different.

If the wavelengths selected by the diffraction gratings **75** formed in the two stripes slightly deviate (on the order of 0.1 nm or larger but less than 3 nm, for example, approximately 0.5 nm), the spectrum obtained by overlapping contains a much larger number longitudinal modes within the wavelength FWHM required in the Raman amplification. The DOP (degree of polarization) can be thereby reduced more effectively.

Further, the wavelengths selected by the diffraction gratings **75** provided in the two stripes may deviate on the order of several nm to several tens of nm (e.g., 3 nm or larger). Normally in the Raman amplification, absolutely different wavelengths, for instance, 1430 nm and 1450 nm, are combined for use as a pumping light source. The two stripes can be designed to emit the 2-wavelength laser beams by providing the diffraction gratings **75** in the two stripes. That is, it follows that the wavelengths are synthesized by the single semiconductor laser module, and hence there is no necessity for the architecture including the two semiconductor laser modules and the externally-attached wavelength synthesizing coupler as in the prior art. This attains the downsizing and saving parts.

In the ninth embodiment, the optical output often needs to be controlled by the respective wavelengths thereof This being the case, as shown in FIG. **8**(C), a separation trench **38** is formed between the two stripes, and the surface of the separation trench **38** is covered with an insulation layer, whereby the two stripes, it is preferable, be electrically separated.

The degree of freedom of the wavelengths of the laser beams outputted from the semiconductor laser module can be increased by forming the two types with an arbitrary combination of the diffraction gratings **75** in the sixth through ninth embodiments discussed above.

As a matter of course, the half-wavelength plate **6** may not be used if the wavelength synthesizing element (e.g., the prism is used as the wavelength synthesizing element) composed of a birefringence substance like rutile when wavelength-synthesizing the beams emitted from the two stripes described above (when the polarization-synthesizing is not required).

Tenth Embodiment

In the double-stripe type semiconductor laser module for emitting the two fluxes of laser beams as exemplified in the first through fifth embodiments, what is normally done for attaching the polarization maintaining fiber formed with FBG as a pigtail fiber is a method of setting it by making the polarizing plane of the two fluxes of laser beams coincident with a polarization retaining axis of the polarization maintaining fiber.

By contrast, the tenth embodiment involves using the semiconductor laser device formed with the two stripes containing the diffraction gratings **75** exemplified in each of the sixth through ninth embodiments and eliminates the necessity for FBG, wherein the optical coupling is attained in such a way that the polarizing plane of the polarization maintaining fiber deviates 45 degrees from the polarizing plane of the semiconductor laser device. This contrivance enables the polarization maintaining fiber to function as a depolarizer and makes it possible to effectively reduce the DOP.

Eleventh Embodiment

FIG. **22**(A) is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with an eleventh embodiment of the present invention.

As shown in FIG. **22**(A), the eleventh embodiment involves using one of the semiconductor laser devices exemplified in each of the sixth through tenth embodiments (which is denoted by the numeral **86** as the representative) each provided with the diffraction gratings **75** in the two stripes **9**, **10**, and there is eliminated the necessity of providing the optical fiber **8** with the beam reflection element **15** such as FBG and so on. Further, an optical isolator **94** that transmits the first beam **K1** and the second laser beam **K2** emitted from the semiconductor laser device **86** only toward the optical fiber **8**, is disposed between the first lens **4** and the second lens **16**. Other than this point, this embodiment is substantially the same as the semiconductor laser module in the first embodiment. The optical isolator disposed therebetween enables for the semiconductor laser device **86** to be stabilized of its operation by preventing the reflection beams. Note that the optical isolator **94** is disposed in a position where the first and second laser beams **K1**, **K2** are parallel, e.g., a position between the prism **5** and the half-wavelength plate **6**, whereby one single optical isolator **94** suffices to correspond. Further, as shown in FIG. **22**(B), an incident surface of the PBC **7** may be given an inclination of angle β (e.g., 4 degrees) in the Z-axis direction for preventing the reflection beams returning to the semiconductor laser device **2**.

Twelfth Embodiment

FIGS. **23** are explanatory diagrams schematically showing a configuration of the semiconductor laser module in accordance with a twelfth embodiment of the present invention.

As shown in FIG. **23**, the twelfth embodiment has such a characteristic configuration that the second laser beams **K2** of the first and second laser beams **K1**, **K2** emitted from the

semiconductor laser device **2** including the two stripes **9**, **10** travels through the central point of the first lens **4** in the axial-line direction of the optical fiber **8**.

In the optical synthesizing element **7** (PBC), the input part **7***b* and the output part **7***c* for the second laser beam K**2** are formed perpendicularly to the optical axis of the second laser beam K**2**, and the input part **7***a* for the first laser beam K**1** is formed with an inclination to these surfaces. Other than this point, this embodiment is substantially the same as the semiconductor laser module in the first embodiment.

According to this configuration, polishing to form the inclined surfaces onto the optical synthesizing element **7** is not needed except for the input part **7***a*, then the optical synthesizing element **7** can be obtained by low cost.

The PBC **7** rotates through approximately 1°. about the Y-axis in order to prevent the reflection return beams to the semiconductor laser device **2**.

According to the twelfth embodiment, the second laser beam K**2** travels through the central point of the first lens **4** in the axial-line direction of the optical fiber **8**, and the first laser beam K**1** is deflected by the first lens **4** with a wider divergence from the second laser beam K**2**, thereby eliminating the necessity of providing the prism and simplifying the configuration.

Moreover, the length of the semiconductor laser module in the optical axial direction can be reduced, and it is therefore possible to decrease the influence of the warp of the package upon the optical output characteristic in the high-temperature state.

Note that the half-wavelength plate **6** and the PBC **7** may be fixed to the same holder member **14** to configure the polarization synthesizing module to facilitate the angular adjustment about the central axis.

Thirteenth Embodiment

FIG. **24** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a thirteenth embodiment of the present invention.

As shown in FIG. **24**, what is characteristic of the thirteenth embodiment is that a plurality (two pieces are given in an example in FIG. **24**) of prisms **5***a*, **5***b* are disposed in the optical-axis direction. The prisms **5***a*, **5***b* have flat input surfaces for inputting the two laser beams K**1**, K**2** and flat output surfaces formed in non-parallel to the input surfaces. Namely, the prism **5***a* is formed with the input and output surfaces, and the prism **5***b* is likewise formed with the input and output surfaces. Other than this point, this embodiment is substantially the same as the semiconductor laser module in the first embodiment. According to the thirteenth embodiment, the two laser beams K**1**, K**2** can be collimated by the prisms with high accuracy. Note that when the two prisms are used, there is performed the wavelength synthesization using the semiconductor laser device exemplified in each of the sixth through ninth embodiments.

Fourteenth Embodiment

FIG. **25** is an explanatory diagram schematically showing a configuration of the semiconductor laser module in accordance with a fourteenth embodiment of the present invention.

As shown in FIG. **25**, the fourteenth embodiment involves the use of the same prisms **5***a*, **5***b* as those in the thirteenth embodiment and has such a characteristic that the incident surface of the prism **5***a* is disposed in a position where the first and second laser beams K**1**, K**2** penetrating the first lens **4** are substantially overlapped with each other. Other than this point, this embodiment is substantially the same as the semiconductor laser module in the first embodiment. According to the fourteenth embodiment, the two laser beams K**1**, K**2** penetrating the prisms **5***a*, **5***b* and substantially overlapped with each other are incident upon the condenser lens **6**, and therefore the PBC **7** is unnecessary, thereby obtaining a more simplified configuration. Note that the prisms **5***a*, **5***b* are herein defined as wavelength synthesizing elements.

Further, the length of the semiconductor laser module in the optical axial direction can be reduced, and it is therefore possible to decrease the influence of the warp of the package upon the optical output characteristic in the high-temperature state.

The semiconductor laser device **2** with the diffraction gratings can be used suitably in this configuration.

Fifteenth Embodiment

FIGS. **26**(A) to **26**(C) are explanatory diagrams showing an example of the photo diode (the light receiving element) **3** in accordance with a fifteenth embodiment of the present invention.

The photo diode **3** may be, as shown in FIG. **26**(A), a waveguide type light receiving element for receiving the beams emitted from the rear-sided edge surfaces of the stripes **9**, **10** of the semiconductor laser device **2**.

Further, a plurality of photo diodes **3** may be, as shown in FIG. **26**(B), provided for receiving and monitoring the respective beams emitted from the other-sided edge surfaces of the stripes **9**, **10** of the semiconductor laser device **2**. In this case, it is preferable that a lens **95** for splitting the laser beams emitted from the semiconductor laser device **2** so as to have a divergence, be disposed between the semiconductor laser device **2** and the photo diode **3**.

Further, the photo diode **3** may receive and monitor the beams reflected by the PBC **7** as shown in FIG. **26**(C).

Based on a result of monitoring by the photo diode **3** as shown in FIGS. **26**(A), **26**(B), **26**(C), for instance, an APC (auto power control) circuit adjust a quantity of the drive current supplied to the semiconductor laser device **2**, thereby controlling the optical output at a constant level.

According to the configuration described above, the APC can be effected on the two stripes independently, and the laser beams K**1**, K**2** can also be kept at an arbitrary light intensity balance.

Sixteenth Embodiment

FIGS. **27**(A) and **27**(B) are explanatory diagrams schematically showing a configuration of the semiconductor laser module in accordance with a sixteenth embodiment of the present invention.

As shown in FIG. **27**(A), the semiconductor laser module in the sixteenth embodiment includes the semiconductor laser device **2**, having the plurality of stripes **9**, **10** (two stripes in an example shown in FIG. **27**) formed with a space therebetween, for emitting a plurality of laser beams K**1**, K**2** from the front-sided edge surfaces of the stripes **9**, **10**. The semiconductor laser module further includes the first lens **4** for converging the plurality of laser beams emitted from the semiconductor laser device on a different focal point, a prism **97** serving as a beam synthesizing element for synthesizing the plurality of laser beams traveling through the first lens **4**, and the optical fiber **8** for receiving the laser beams emerging from the prism **97** and letting the beams travel outside.

The stripes **9**, **10** of the semiconductor laser device **2** include the diffraction gratings **75** described above, and the laser beams are emitted with different wavelengths from the stripes **9**, **10**.

The sixteenth embodiment involves, as shown in FIG. **27**(B), the use of a wedge-shaped prism as the prism **97**. The incident surface of this wedge-shaped prism is formed with a wavelength selection filter **97***a* that reflects or transmits the beam in accordance with the wavelength. The wavelength selection filter **97***a* is constructed of, e.g., dielectric multi-layers. The wavelength selection filter **97***a* reflects the first laser beam **K1** and transmits the second laser beam **K2**.

FIG. **28** is a graph showing a beam transmissivity when the beams enter the wavelength selection filter **97***a*. As shown in FIG. **28**, the beam transmissivity differs depending on a difference in an incident angle upon the wavelength selection filter **97***a*. When the incident angle is θb the filter **97***a* transmits almost 100% of the incident beams of which the wavelength is $\lambda x(\theta b)$ or less, and reflects almost 100% of the incident beams of which the wavelength is longer than $\lambda x(\theta b)$. Further, when the incident angle is θa the filter **97***a* transmits almost 100% of the incident beams of which the wavelength is $\lambda x(\theta a)$ or less, and reflects almost 100% of the incident beams of which the wavelength is longer than $\lambda x(\theta a)$.

Moreover, the exit surface of the wedge-shaped prism **97** is formed with a total reflection layer **97***b* that reflects the beams of all the wavelengths, and a reflection preventive layer **97***c* that prevents the beam reflection.

According to the sixteenth embodiment, the wavelength of the laser beam **K1** is set to λa the incident angle of the laser beam **K1** upon the wavelength selection filter **97***a* is set to θa the wavelength of the laser beam **K2** is set to λb and the incident angle of the laser beam **K2** upon the wavelength selection filter **97***a* is set to θb.

The first laser beam **K1**, when entering the first input part **I1** of the wavelength selection filter **97***a* at the angle θa penetrates it at an angle $\theta' a$ and at a refractive index Np. Then, the first laser beam **K1** is reflected at an angle θs (θa+wedge angle ψ) from the total reflection layer **7***b* (the reflection part) and reaches the first input part **I1** for the second laser beam **K2**.

The second laser beam **K2**, when entering the second input part **12** of the wavelength selection filter **97***a* at the angle θb penetrates it at the angle $\theta' b$ and at the refractive index Np. The reflected first laser beam **K1** is reflected at an angle $\theta' b$ ($2\theta s$+wedge angle ψ) from the second input part **I2** of the wavelength selection filter **97***a*. Therefore, the first and second laser beams **K1**, **K2** are synthesized. The synthesized laser beam (**K1**+**K2**) travels through the output part O of the reflection preventive layer **97***c*.

The optical module in the sixteenth embodiment is designed based on, e.g., the following numerical values and can be thereby embodied.

$\psi=1°$, $\theta' a=8°$, $\theta' b=10°$, $Np=1.5$, $\theta a=12.050°$, $\theta b=15.098°$, an angle αa (made by the optical axis C of the first lens **4** and the first laser beam **K1**)$=(\theta a-\theta b)/2=-1.524°$, an angle αb (made by the optical axis C of the first lens **4** and the second laser beam **K2**)$=(\theta b-\theta a)/2=1.524°$, a first lens focal length **f2**=720 μm, a distance da (between the first stripe **9** and the optical axis C of the first lens **4**)$=-\tan \alpha a \cdot$**f2**=19.16 μm, a distance db (between the second stripe **10** and the optical axis C of the first lens **4**)$=-\tan \alpha b \cdot$**f2**=−19.16 μm, a thickness t (of the prism **97** in the incident position of the first laser beam **K1**)=1 mm, an interval Δy (between the incident positions of the first and second laser beams **K1**, **K2**)$\approx 2(\tan \theta a+\psi)t \approx 0.462$ mm, an on-optical-axis distance D (from the focal position of the first lens **4** to the edge surface of the PBC **7**)$\approx \Delta y/(\theta b-\theta a)=8.7$ mm, $\lambda a=1480$ nm, $\lambda b=1460$ nm. $\lambda x(\theta b)=1470$ nm, $\lambda x(\theta a)=1486.5$ nm, and a cut-off wavelength $\lambda \times 0$ (at the incident angle of 0 degree)=1522.6 nm.

The sixteenth embodiment involves the use of the first lens **4** for converging the plurality of laser beams emitted from the semiconductor laser device **2** on the different focal point, whereby both of a beam size and an image magnification are reduced, and positional and angular tolerances can be enlarged. This effect is not limited to the sixteenth embodiment but common to the case where the first lens **4** is used as a converging optical system.

Next, the coupling efficiency when the laser beams emitted from the semiconductor laser device **2** are coupled to the optical fiber, will be considered based on the Gaussian beam approximation. What may be considered in this case is the coupling of the beam emitted from the semiconductor laser device **2** and projected by the first lens **4** and the beam emerging from the optical fiber **8** and projected by the second lens **16**. Focal lengths of the lenses **4**, **16** are selected so that mode field radii of the respective projected beams are equalized.

Referring to FIG. **32**, **f2** is a focal length of the first lens **4**, **f3** is a focal length of the second lens **16**, WLD is a mode filed radius of a point p spaced with the focal length **f2** of the first lens **4**, W_f is a mode filed radius of a point q spaced with the focal length **f3** of the second lens **16**, i.e., an interval between the focal positions of the first lens **4** and the second lens **16**.

The image magnification M is given such as $M \approx W_f/W_{LD}$= **f2**/**f3**, and hence, if w_f=5 μm and w_{LD}=1.7 μm, **f2**=720 μm, **f3** is given such as **f3**=2100 μm.

In this case, the mode filed radius of the beams emitted from the semiconductor laser device **2** and the optical fiber **8** and projected by the first lens **4** and the second lens **16**, is 198 μm. An axial deviation tolerance at this time is substantially equal to a deviation in the case of 200 μm.

Especially for synthesizing the two laser beams of the laser of which a maximum angle difference as strict as $\Delta\theta=0.013°$, it is required that a maximum angle difference between the beams be set on the order of 0.013°. For attaining this, the respective elements may be manufactured so that the wedge angle $\psi=1+0.0013°$, da=−db=19.16±0.03 μm. **f2**=720±0.7 m. The coupling efficiency of each of the stripes **9**, **10** to the optical fiber **8** can be thereby set to 80% or greater.

Seventeenth Embodiment

FIGS. **29**(A) and **29**(B) are explanatory diagrams schematically showing a configuration of the semiconductor laser module in accordance with a seventeenth embodiment of the present invention.

As shown in FIG. **29**(A), the semiconductor laser module in the seventeenth embodiment includes the semiconductor laser device **2**, having the plurality of stripes **9***a*, **9***b*, **9***c* (three stripes in an example shown in FIG. **29**) formed with a space therebetween, for emitting the plurality of laser beams K1, K2, K3 from the front-sided edge surfaces of the stripes **9***a*, **9***b*, **9***c*. The semiconductor laser module further includes the first lens **4** for converging the plurality of laser beams emitted from the semiconductor laser device each on a different focal point, the prism **97** for synthesizing the plurality of laser beams traveling through the first lens **4**, and the optical fiber **8** for receiving the laser beams emerging from the prism **97** and letting the beams travel outside.

The stripes **9**_a_, **9**_b_, **9**_c_ of the semiconductor laser device **2** include the diffraction gratings **75** described above, and the laser beams are emitted with different wavelengths from the stripes **9**_a_, **9**_b_, **9**_c_.

Further, as shown in FIG. **30**, the exit surface of the wedge-shaped prism is formed with the total reflection layer (reflection part) **97**_b_ for reflecting the beams of all the wavelengths, and a reflection preventive layer (output part) **97**_c_ for preventing the reflection.

According to the seventeenth embodiment, the wavelength of the laser beam K**1** is set to λa, the incident angle of the laser beam K**1** upon the wavelength selection filter **97**_a_ is set to θa, the wavelength of the laser beam K**2** is set to λb, the incident angle of the laser beam K**2** upon the wavelength selection filter **97**_a_ is set to θb, the wavelength of the laser beam K**3** is set to λc, and the incident angle of the laser beam K**3** upon the wavelength selection filter **97**_a_ is set to θc.

The first laser beam K**1**, when entering the first input part I**1** of the wavelength selection filter **97**_a_ at the angle θa, penetrates it at the angle $\theta' a$ and at the refractive index Np. Then, the first laser beam K**1** is reflected at an angle θs (θa+wedge angle ψ) from the total reflection layer **7**_b_ (the reflection part) and reaches the first input part I**1** for the second laser beam K**2**.

The second laser beam K**2**, when entering the second input part I**2** of the wavelength selection filter **97**_a_ at the angle θb, penetrates it at the angle $\theta' b$ and at the refractive index Np. The reflected first laser beam K**1** is reflected at the angle $\theta' b$ (θs+wedge angle ψ) from the wavelength selection filter **97**_a_, and therefore the first and second laser beams K**1**, K**2** are synthesized. The synthesized laser beam (K**1**+K**2**) is reflected at an angle θt ($\theta' b$+wedge angle ψ) from the total reflection layer **97**_b_ and reaches a third input part **13** for the third laser beam K**3**.

The third laser beam K**3**, when entering the third input part **13** of the wavelength selection filter **97**_a_ at the angle θc, penetrates it at the angle $\theta' c$ and at the refractive index Np. The reflected synthesized laser beam (K**1**+K**2**) is reflected at an angle $\theta' c$ (θt+wedge angle ψ) from the third input part **13** of the wavelength selection filter **97**_a_, and hence the third laser beam K**3** and the synthesized laser beam (K**1**+K**2**) are synthesized. The synthesized laser beam (K**1**+K**2**+K**3**) penetrates the reflection preventive layer **97**_c_.

According to the seventeenth embodiment, a light path correction prism **96** for correcting the light path of the first laser beam K**1** is disposed in front of the prism **97** (see FIG. **31**).

The light path correction prism **96** is capable of correcting axial deviations

(Δx, Δy, $\Delta\theta$, Δz) of the Gaussian beams. Herein, the following relationships are established:

$$\mathrm{Sin}\ \theta p = Nc \sin \theta'$$

$$\Delta y = L \cdot \tan(\theta p - \theta p')/(1 - \tan(\theta p - \theta p')\tan \theta p) \approx L\theta(\mathrm{rad}) \cdot (1 - 1/N), \text{ and}$$

$$\Delta z \approx (1 - 1/Nc)L$$

where L is the length of the light path correction prism **96** in the optical axis direction, θp is the incident angle, $\theta p'$ is the exit angle, and Nc is the refractive index. With respect to the axial deviation Δx, the light path correction prism **96** corrects the incident position of the first laser beam K**1**. Further, an incident position Δy**1** can be minutely adjusted by rotating the light path correction prism **96**. An incident position Δy**2** can be adjusted by moving forward and backward the light path correction prism **96**.

With respect to $\Delta\theta$, when ψ=1±0.050, a maximum difference between the distances da and dc is set to ±0.1 μm, whereby the laser beams can be multiplexed at a low loss without any adjustment.

With respect to Δz, the reflection occurs a plurality of times at the wedge-shaped prism, and therefore the beam converging point of every laser beam differs. If the light path correction prism **96** is not inserted, there occurs a light path difference on the order of 2.5 mm between the first and third laser beams K**1**, K**3**.

According to the seventeenth embodiment, the light path correction prism **96** is inserted, whereby the difference in the light path length can be substantially completely corrected. Similarly, the light path correction prism **96** for the second laser beam K**2** may be inserted, thereby correcting difference in the light path length.

According to the seventeenth embodiment, the light path correction prism **96** is provided on the light path for the laser beam, and hence, even if the maximum difference between the elements is comparatively slackened, it is possible to obtain approximately 80% or more of the optical coupling of each laser beam to the optical fiber **8**.

Note that the first lens **4** widens the divergence between the plurality of laser beams which are independent without being overlapped with each other, and therefore the light path correction prism **96** can be inserted in the seventeenth embodiment.

The optical module in the seventeenth embodiment is designed based on, e.g., the following numerical values and can be thereby embodied.

The light path for the second laser beam K**2** is coincident with the central axis C of the first lens **4**.

ψ=1°, $\theta' a$=8°, $\theta' b$=10°, $\theta' c$=12°, Np=1.5, θa=12.050°, θb=15.10°, θc=18.17°, the angle αa (made by the optical axis C of the first lens **4** and the first laser beam K**1**)=$\theta a - \theta b$=−3.05°, the angle αc (made by the optical axis C of the first lens **4** and the third laser beam K**3**)=$\theta c - \theta a$=3.07°, the first lens focal length f**2**=720 μm, the distance da (between the first stripe **9**_a_ and the optical axis C of the first lens **4**)=−tan $\alpha a \cdot$f**2**=−38.4 μm, a distance dc (between the third stripe **9**_c_ and the optical axis C of the first lens **4**)=−tan $\alpha b \cdot$f**2**=38.6 μm, a thickness t (of the prism **97** in the incident position of the first laser beam K**1**)=1 mm, an interval Δy**1** (between the incident positions of the first and second laser beams K**1**, K**2**)≈2(tan $\theta a + \psi$)t≈0.462 mm, an interval Δy**2** (between the incident positions of the second and third laser beams K**2**, K**3**)≈**2**(tan $\theta a + 2\psi$/cos $2\theta a + \psi$)t≈0.535 mm, an on-optical-axis distance D (from the focal position of the first lens **4** to the edge surface of the prism **97**)≈Δy**2**/($\theta c \cdot \theta b$)(rad)=10.0 mm, λa=1490 nm, λb=1470 nm, λc=1450 nm. $\lambda x(\theta c)$=1460 nm, $\lambda x(\theta b)$=1483.57 nm, $\lambda x(\theta a)$=1502.77 nm, and the cut-off wavelength λx**0** (at the incident angle of 0 degree)=1536.62 nm.

Further, in the light path correction prism **96**, when Δy=D($\theta b - \theta a$)(rad)−Δy**1**=0.070 nm, L=3.5 nm and Nc=3.4 (silicon), the prism incident angle θ1.25° and a light path length reduction Δz≈(1−1/Nc)L≈2.5 nm.

In the case of generalizing the sixteenth and seventeenth embodiments, when the laser beams having first to n-th wavelengths are emitted from the first to n-th (n is an integer that is 2 or larger) stripes of the semiconductor laser device **2**, the prism **97** includes first to n-th input parts upon which the laser beams of the first through n-th wavelengths are incident, a reflection part for totally reflecting the laser beams, and an output part. The i-th (i includes all the integers of 2 to n) input parts and the reflection part function such that the (i-1)th beam entering the light synthesizing element from

the (i-1)th input part is reflected by the reflection part toward the i-th input part and further reflected within the i-th input part in the traveling direction of the beam of the i-th wavelength, and synthesized with the beam of the i-th wavelength. The synthesized beams having the first to n-th wavelengths are coupled to the optical fiber via the output part.

Eighteenth Embodiment

An eighteenth embodiment is that of the semiconductor laser module exemplified in one of the first through seventeenth embodiments, as applied to a Raman amplifier.

FIG. **33** is a block diagram showing a configuration of the Raman amplifier for the eighteenth embodiment of the present invention. This Raman amplifier is used in, e.g., a WDM communication system. As shown in FIG. **33**, a Raman amplifier **48** includes an input unit **49** for inputting the signal beam, an output unit **50** for outputting the signal beam, an optical fiber (amplification fiber) **51** through which the signal light is transmitted between the input unit **49** and the output unit **50**, a pumping beam generating unit **52** for generating the pumping beam, and a WDM coupler **53** for multiplexing the pumping beam generated by the pumping beam generating unit **52** with the signal beam transmitted through the optical fiber (amplification fiber) **51**, and optical isolators **54** that transmit only the signal beam traveling from the input unit **49** toward the output unit **50**, are provided between the input unit **49** and the WDM coupler **53** and between the output unit **50** and the WDM coupler **53**.

The pumping beam generating unit **52** includes a plurality semiconductor laser modules for emitting the laser beams having wavelength ranges different from each other in the eighteenth embodiment, and a WDM coupler **55** for synthesizing the laser beams emitted from the semiconductor laser modules M.

The pumping beams emitted from the semiconductor laser modules M are synthesized by the WDM coupler **55** through a polarization maintaining fiber **55***a*, and exit the pumping beam generating unit **52**.

The pumping beams generated by the pumping beam generating unit **52** are coupled to the optical fiber **51** by the WDM coupler **53**. The signal beams inputted from the input unit **49** are multiplexed with the pumping beams and amplified in the optical fiber **51**, then travel through the WDM coupler **53** and are outputted from the output unit **50**.

The signal beams (amplified signal beams) amplified within the optical fiber **51** are inputted to a monitor beam distribution coupler **56** via the WDM coupler **53** and the optical isolators **54**. The monitor beam distribution coupler **56** emits some proportion of the amplified signal beams to a control circuit **57**, and the remaining amplified signal beams are outputted from the output unit **50**.

The control circuit **57** controls a laser emission state, e.g., a light intensity of each semiconductor laser module M on the basis of some amplified signal beams inputted thereto, and performs feedback control so that a gain of the optical amplification comes to have a flat characteristic.

In this Raman amplifier **48**, if the semiconductor laser module incorporating the semiconductor laser device with the diffraction gratings **75** provided within the stripes is used, the FBG for the laser oscillation stabilization, is not wanted. As a result, it is possible to reduce both of the size and weight of the Raman amplifier and also the cost thereof.

Further, this Raman amplifier can reduce a greater amount of relative intensity noises (RIN) than by the semiconductor laser module using FBG and is therefore capable of restraining the fluctuation in the Raman gain and performing stable Raman amplification.

Furthermore, the semiconductor laser device with the diffraction gratings **75** provided in the stripes has the plurality of oscillation modes, and is therefore capable of emitting the high-output pumping beams without causing the stimulated Brillouin scattering, whereby the stable and high Raman gain can be obtained.

Further, the Raman amplifier shown in FIG. **33** is categorized as a rear optical pumping type, however, as discussed above, the semiconductor laser module emits the stable pumping beams. Hence, the Raman amplifier is, regardless of whether a front optical pumping type or a bidirectional optical pumping type, capable of performing the stable Raman amplification.

The Raman amplifier sown in FIG. **33** can be, as explained above, applied to the WDM communication system. FIG. **34** is a block diagram showing architecture of the WDM communication system to which the Raman amplifier shown in FIG. **33** is applied.

Referring to FIG. **34**, the optical signals having wavelengths **λ1** to λn that are transmitted from a plurality of transmitters **87**, are multiplexed by an optical multiplexer **88** and converged at one length of optical fiber **89**. A plurality of Raman amplifiers **90** each corresponding to the Raman amplifier shown in FIG. **33** are disposed according to a distance on the transmission path of the optical fiber **89**, and amplify attenuated optical signals. The signals transmitted on the optical fiber **89** are demultiplexed by an optical demultiplexer **91** into optical signals having the plurality of wavelength **λ.1** to λn, and received by a plurality of receivers **92**. Note that an ADM (Add/Drop Multiplexer) **93** for adding and fetching the optical signal having an arbitrary wavelength might be provided on the optical fiber **89**.

The present invention can be modified in many forms within the range of the technical items set forth in the following claims without being limited to the embodiments discussed above.

In the semiconductor laser modules M in the embodiments discussed above, the semiconductor laser device **2** and the holder member **14** are cooled by the same cooling device **20**, however, the temperatures of the semiconductor laser device **2** and the holder member **14** may be controlled independently by use of separate cooling devices.

Further, the polarization rotating element involves the use of the half-wave plate **6**, however, the polarizing plane may be rotated by use of, for instance, the Faraday element. In this case, the Faraday element is disposed inwardly of the coil, and an intensity of a magnetic field applied to the Faraday element is set variable corresponding to a magnitude of the electric current flowing through the coil. With this arrangement, a fluctuation in the wavelength of the laser beam and a fluctuation in the rotational angle of the polarizing plane due to a fluctuation in the temperature, can be individually compensated by adjusting the magnitude of the electric current flowing through the coil.

Moreover, the semiconductor laser module in each of the embodiments discussed above can be used as not only the pumping light source for the Raman amplification but also, for example, a 0.98 μm EDFA pumping light source. Moreover, the semiconductor laser module in each of the embodiments of the present invention can be used as a signal light source.

Further, the number of the stripes formed in the present semiconductor laser device **2** is not limited to 2 or 3 but may be 4 or more.

Additional numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.

What is claimed is:

1. A semiconductor laser module comprising:

a single semiconductor laser device having a multi-layer semiconductor structure with a first light emitting stripe and at least one other light emitting stripe formed therein which are aligned to respectively emit a first laser beam and at least one other laser beam through one edge surface of said multi-layer semiconductor structure, said first beam and said second beam being separated by a first predetermined distance when emitted through said one edge surface;

a first lens positioned so that the first laser beam and the at least one other laser beam emitted from the semiconductor laser device are incident thereon, the first lens configured to deflect at least one of the first laser beam and the at least one other laser beam;

a beam synthesizing member positioned downstream, in a beam propagating direction, of said first lens, said beam synthesizing member including

a first input part on which the first laser beam is incident,

at least one other input part on which the at least one other laser beam is incident, said first laser beam and said second laser beam being separated by a second predetermined distance when incident on said beam synthesizing member, and

an output part from which the first laser beam emerging from the first input part and the at least one other laser beam emerging from the at least one other input part are combined and emitted as a combined laser beam; and

an optical fiber positioned to receive the combined laser beam therein, wherein

said first predetermined distance being smaller than said second predetermined distance.

2. The semiconductor laser module according to claim **1**, further comprising:

a second lens configured to couple the combined laser beam to the optical fiber.

3. The semiconductor laser module according to claim **2**, wherein:

the first lens and the second lens are positioned so that the first laser beam and the at least one other laser beam are focused to a point between the first lens and the second lens.

4. The semiconductor laser module according to claim **1**, wherein:

the first lens is positioned so that an optical axis of the first laser beam emitted from the first light emitting stripe and an optical axis of the at least one other laser beam emitted from the at least one other light emitting stripe are substantially symmetric about a center axis of the first lens.

5. The semiconductor laser module according to claim **1**, further comprising:

a light receiving element positioned to receive light emitted from the first laser emitting stripe and the at least one other laser emitting stripe.

6. The semiconductor laser module according to claim **5**, wherein:

the light receiving element is positioned to receive and monitor the first laser beam and the at least one other laser beam emitted from an other edge surface of the semiconductor laser device.

7. The semiconductor laser module according to claim **5**, wherein:

the light receiving element is a waveguide light receiving element.

8. The semiconductor laser module according to claim **5**, further comprising:

a lens disposed between the semiconductor laser device and the light receiving element to split the first laser beam and the at least one other laser beam so as to expand a separation between the first laser beam and the at least one other laser beam.

9. The semiconductor laser module according to claim **5**, wherein:

the light receiving element is configured to receive and monitor respective portions of the first laser beam and the at least one other laser beam reflected by an arbitrary optical component arranged between the semiconductor device and optical fiber.

10. The semiconductor laser module according to claim **1**, wherein:

the first light emitting stripe and the at least one other light emitting stripe in the semiconductor laser device extend parallel to each other.

11. The semiconductor laser module according to claim **10**, wherein:

the first light emitting stripe and the at least one other light emitting stripe are the only light emitting stripes in the semiconductor laser device.

12. The semiconductor laser module according to claim **11**, wherein:

the first light emitting stripe and second light emitting stripe in the semiconductor laser device are separated by not more than 100 μm.

13. The semiconductor laser module according to claim **1**, wherein:

the first light emitting stripe and the at least one other light emitting stripe in the semiconductor laser device are inclined relative to each other.

14. The semiconductor laser module according to claim **1**, wherein:

the first light emitting stripe and the at least one other light emitting stripe in the semiconductor laser device are configured to be simultaneously driven.

15. The semiconductor laser module according to claim **1**, wherein:

the first light emitting stripe and the at least one other light emitting stripe in the semiconductor laser device are configured to be independently driven in a way that electrically insulates at least one side of a positive electrode and a negative electrode of the first light emitting stripe and the at least one other light emitting stripe.

16. The semiconductor laser module according to claim **1**, wherein:

the semiconductor laser device is an InP-series BH buried heterostructure laser.

17. The semiconductor laser module according to claim **1**, wherein:

the semiconductor laser device is a GaAs-series ridge waveguide laser.

18. The semiconductor laser module according to claim **1**, wherein:

the semiconductor laser device is configured to operate as a pumping light source in an inclusive range of 1300 nm through 1550 nm for a Raman amplifier.

19. The semiconductor laser module according to claim 1, wherein:

the semiconductor laser device is configured to operate as a pumping light source in at least one of a 980 nm band and 1480 nm band for EDFA.

20. The semiconductor laser module according to claim 1, wherein:

the beam synthesizing member comprises at least one of a polarization beam combiner and a prism.

21. The semiconductor laser module according to claim 20, wherein:

the polarization beam combiner is a birefringence element configured to propagate any one of the first laser beam and the at least one other laser beam as a normal ray and to propagate another of the at least one of the first laser beam and the at least one other laser beam as an extraordinary ray.

22. The semiconductor laser module according to claim 20, wherein:

the first input part and the at least one other input part of the beam synthesizing member are inclined relative to each other.

23. The semiconductor laser module according to claim 20, wherein:

the first input part and the at least one other input part of the beam synthesizing member are a common part that is perpendicular to an optical axial direction of the semiconductor laser module.

24. The semiconductor laser module according to claim 20, wherein:

the first input part and the at least one other input part of the beam synthesizing member are a common part that is not perpendicular to an optical axial direction of the semiconductor laser module.

25. The semiconductor laser module according to claim 20, wherein:

the beam synthesizing member is further configured to multiplex at least three laser beams.

26. The semiconductor laser module according to claim 1, further comprising:

a light path correction prism positioned between the first lens and the beam synthesizing member.

27. The semiconductor laser module according to claim 1, wherein:

the semiconductor laser device and the first lens are disposed with inclinations at predetermined angles to an optical axial direction of the semiconductor laser module so that the first laser beam is directed to propagate in an axial direction of the optical fiber.

28. The semiconductor laser module according to claim 1, further comprising:

a prism disposed between the first lens and the beam synthesizing member positioned to receive and collimate the first laser beam and the at least one other laser beam.

29. The semiconductor laser module according to claim 1, further comprising:

a polarization rotating element positioned between the first lens and the beam synthesizing member, wherein the polarization rotating element is configured to rotate a polarizing plane of at least one of the first laser beam and the at least one other laser beam.

30. The semiconductor laser module according to claim 29, wherein:

the polarization rotating element is a half wave plate.

31. The semiconductor laser module according to claim 1, further comprising:

a beam reflection part configured to reflect a predetermined wavelength of the combined laser beam back to the semiconductor laser device.

32. The semiconductor laser module according to claim 31, wherein:

the beam reflection part includes a fiber Bragg grating.

33. The semiconductor laser module according to claim 1, wherein:

the optical fiber is a polarization maintaining fiber.

34. The semiconductor laser module according to claim 1, wherein:

at least one of the first light emitting stripe and the at least one other light emitting stripe of the semiconductor laser device include a diffraction grating.

35. The semiconductor laser module according to claim 34, wherein:

the diffraction grating of at least one of the first light emitting stripe and the at least one other light emitting stripe of the semiconductor laser device are disposed uniformly across an entire cavity length of the semiconductor device.

36. The semiconductor laser module according to claim 35, wherein:

the diffraction grating of at least one of the first light emitting stripe and the at least one other light emitting stripe of the semiconductor laser device extend along a cavity length of the semiconductor device of at least 800 μm and are configured to produce a plurality of longitudinal oscillation wavelengths within a predetermined wavelength band.

37. The semiconductor laser module according to claim 34, wherein:

the diffraction grating of at least one of the first light emitting stripe and the at least one other light emitting stripe of the semiconductor laser device are disposed uniformly across at least one portion, but not an entire length, of a cavity length of the semiconductor device.

38. The semiconductor laser module according to claim 34, wherein:

the diffraction grating of at least one of the first light emitting stripe and the at least one other light emitting stripe of the semiconductor laser device comprises a periodically changed grating period.

39. The semiconductor laser module according to claim 34, wherein:

the diffraction gratings of the first light emitting stripe and the at least one other light emitting stripe of the semiconductor laser device are configured so that wavelengths emitted by the first light emitting stripe and the at least one other light emitting stripe are selectively set to be a same wavelength.

40. The semiconductor laser module according to claim 34, wherein:

the diffraction gratings of the first light emitting stripe and the at least one other light emitting stripe of the semiconductor laser device are configured so that wavelengths emitted by the first light emitting stripe and the at least one other light emitting stripe are selectively set to be different.

41. The semiconductor laser module according to claim 40, wherein:

the first light emitting stripe and the at least one other light emitting stripe in the semiconductor laser device are

configured to be independently driven in a way that electrically insulates at least one side of a positive electrode and a negative electrode of the first light emitting stripe and the at least one other light emitting stripe.

42. The semiconductor laser module according to claim **1**, further comprising:

an optical isolator positioned between the first lens and the beam synthesizing member where the first laser beam and the at least one other laser beam are parallel relative to each other, wherein the optical isolator is configured to stabilize the semiconductor laser module by preventing a laser beam reflection.

43. The semiconductor laser module according to claim **1**, further comprising:

a cooling device configured to cool the semiconductor laser device; and

a base plate module having a first base plate on which the semiconductor laser device is fixed and a second base plate disposed onto the first base plate and on which the beam synthesizing member is fixed.

44. The semiconductor laser module according to claim **43**, wherein:

the cooling device is a heat sink comprising a plurality of Peltier elements disposed under the base plate module; and

the cooling device is configured to keep a constant temperature and to increase and stabilize the first laser beam and the at least one other laser beam emitted from the semiconductor laser device.

45. The semiconductor laser module according to claim **43**, further comprising:

a thermistor configured to detect a change in temperature due to heat transferred from the semiconductor laser device and to input a signal into the cooling device.

46. An optical amplifier comprising:

a pump beam generator having a plurality of semiconductor laser modules each having a multi-layer semiconductor structure configured to emit combined laser beams, with each semiconductor laser module including

a single semiconductor laser device having a first light emitting stripe and at least one other light emitting stripe which are aligned to respectively emit a first laser beam and at least one other laser beam through one edge surface of said multi-layer semiconductor structure, said first beam and said second beam being separated by a first predetermined distance when emitted through said one edge surface,

a first lens positioned so that the first laser beam and the at least one other laser beam emitted from the semiconductor laser device are incident thereon, the first lens configured to further separate the first laser beam and the at least one other laser beam,

a beam synthesizing member positioned downstream, in a beam propagating direction, of said first lens, said beam synthesizing member including

a first input part on which the first laser beam is incident, at least one other input part on which the at least one other laser beam is incident, said first laser beam and said second laser beam being separated by a second predetermined distance when incident on said beam synthesizing member, and

an output part from which the first laser beam emerging from the first input part and the at least one other laser beam emerging from the at least one other input part are combined and emitted as a combined laser beam,

an optical fiber positioned to receive the combined laser beam therein;

a wave division multiplex coupler configured to synthesize the combined laser beams emitted by the plurality of semiconductor laser modules; and

an amplification medium configured to amplify an optical signal using said multiplexed laser beams transmitted from said wave division multiplex coupler, wherein

said first predetermined distance being smaller than said second predetermined distance.

47. The optical amplifier of claim **46**, wherein:

the plurality of semiconductor laser modules are each configured to emit the combined laser beam at different control wavelengths.

48. The optical amplifier according to claim **46**, wherein:

at least one of the first light emitting stripe and the at least one other light emitting stripe includes a diffraction grating.

49. The optical amplifier according to claim **46**, wherein:

the optical fiber is a polarization maintaining fiber.

50. The optical amplifier according to claim **46**, wherein:

the pump beam generator is coupled to the amplification medium by a wave division multiplex coupler.

51. The optical amplifier according to claim **46**, wherein:

the pump beam generator is coupled to a control mechanism including a monitor beam distribution coupler coupled to the amplification medium and a control circuit connected between the monitor beam distribution coupler and the pump beam generator, wherein the control mechanism is configured to control the output of the plurality of semiconductor laser modules.

52. A semiconductor laser module, comprising:

means for producing a first laser beam and a second laser beam from a single semiconductor laser device separated by a first predetermined distance;

means for deflecting at least one of the first laser beam and the second laser beam so as to further separate said first laser beam and said second laser beam by an amount greater than said first predetermined distance; and

means for combining the first laser beam and the second laser beam into a combined laser beam, said means for combining being positioned downstream of said means for deflecting in a beam propagating direction.

53. A semiconductor laser module according to claim **52**, further comprising:

means for polarization rotating at least one of the first laser beam and the second laser beam.

54. A semiconductor laser module according to claim **52**, further comprising:

means for producing a plurality of longitudinal oscillation wavelengths within a predetermined wavelength band.

55. A semiconductor laser module according to claim **52**, further comprising:

means for stabilizing a wavelength of the combined laser beam.

56. A semiconductor laser module according to claim **52**, further comprising:

means for coupling the combined laser beam onto an optical fiber.

57. A method for generating a combined laser beam, comprising steps of:

producing a first laser beam and a second laser beam from a single semiconductor laser device separated by a first predetermined distance;

further separating the first laser beam and a second laser beam by an amount greater than said first predetermined distance;

and combining the first laser beam and the second laser beam into a combined laser beam after said first and second laser beams are further separated by said amount greater than said first predetermined distance.

58. A method for generating a combined laser beam according to claim **57**, further comprising a step of:

polarization rotating at least one of the first laser beam and the second laser beam.

59. A method for generating a combined laser beam according to claim **57**, further comprising a step of:

producing a plurality of longitudinal oscillation wavelengths within a predetermined wavelength band.

60. A method for generating a combined laser beam according to claim **57**, further comprising a step of:

stabilizing a wavelength of the combined laser beam.

61. A method for generating a combined laser beam according to claim **57**, further comprising a step of:

coupling the combined laser beam onto an optical fiber.

62. The semiconductor laser module according to claim **29**, wherein: the polarization rotating element is a Faraday rotator configured to have an adjustable rotation angle.

63. A method for generating a combined laser beam according to claim **58**, wherein: said step of polarization rotating comprises a substep of adjusting a polarization rotation angle with a Faraday rotator.

64. The optical amplifier of claim **46**, further comprising: an fiber Bragg grating optical output fiber.

65. A semiconductor laser module according to claim **52**, wherein: said means for producing includes means for stabilizing a wavelength of at least one of the first laser beam and the second laser beam.

66. The optical amplifier of claim **46**, further comprising:

an fiber Bragg grating optical output fiber.

67. A semiconductor laser module according to claim **52**, wherein:

said means for producing includes means for stabilizing a wavelength of at least one of the first laser beam and the second laser beam.

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